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Respirable Dust Control

Proceedings: Bureau of Mines Technology Transfer Seminars,
Pittsburgh, Pa., September 21, 1976
and St. Louis, Mo., September 23, 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

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Proceedings: Bureau of Mines Technology Transfer Seminars, Pittsburgh, Pa., September 21, 1976 and St. Louis, Mo., September 23, 1976

Compiled by Staff–Mining Research, Bureau of Mines, Pittsburgh, Pa.

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

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CONTENTS

	Page
Abstract	1
Introduction	1
Overview of the respirable dust research program, by John A. Breslin	3
MESA's respirable dust enforcement program, by Joseph Lamonica	5
Respirable dust measurement, by John A. Breslin	10
Reduced generation of airborne respirable dust through deep-cutting continuous miners, by Sigmund Black and Robert Schmidt	24
Guidelines for selecting dust collectors for use in coal mines, by Edward F. Divers	37
Control of respirable dust by ventilation, by Natesa I. Jayaraman	48
Water infusion for dust control, by Joseph Cervik	63
Wethead dust control, by Kelly C. Strebig	78
Control of respirable dust by improved water sprays, by Welby G. Courtney and Lung Cheng	92
Personal protection against respirable dust, by Thomas E. Rosendahl	109

RESPIRABLE DUST CONTROL

Proceedings: Bureau of Mines Technology Transfer Seminars, Pittsburgh, Pa., September 21, 1976 and St. Louis, Mo., September 23, 1976

Compiled by

Staff–Mining Research

ABSTRACT

These proceedings consist of an introduction, nine descriptive papers, and a summary. The first paper is an overview of the respirable dust research program, the second paper describes the Mining Enforcement and Safety Administration's proposed changes in the respirable dust enforcement program, and the third paper describes respirable dust measurement. The remaining papers, by Bureau and contractor personnel, describes methods of reducing the amount of respirable dust to which coal miners are exposed.

Of the six methods of reducing exposure to respirable dust described, two are methods of preventing or reducing the amount of respirable dust raised during mining operations, two are methods of collecting or removing dust after it has been released into the mine atmosphere, and two describe methods that are combinations of prevention and collecting.

INTRODUCTION

This report contains the 10 papers presented at the Bureau of Mines Technology Transfer Seminars held in Pittsburgh, Pa., on September 21, 1976, and in St. Louis, Mo., on September 23, 1976. The seminars are part of the Bureau's ongoing program to apprise the mining industry of the results of Bureau of Mines research. It is hoped that the prompt dissemination of this information will expedite in-mine application of healthier, more efficient mining techniques.

The papers presented in this report provide current information on problems of respirable dust generation, suppression, and control. Respirable coal mine dust is particulate matter less than approximately 5.0 micrometers in diameter. These airborne particles can accumulate in the lungs and, after long-term exposure, can lead to coal miners' pneumoconiosis, more commonly known as "black lung."

The Bureau of Mines program to combat respirable coal dust grew out of the mandate to the U.S. Department of the Interior from Congress, as described in the Federal Coal Mine Health and Safety Act of 1969. A paper outlining

proposed changes in the Dust Enforcement Program, now administered by the Mining Enforcement and Safety Administration, is included in this report.

Throughout the Proceedings, mention of trade names is made to facilitate understanding and does not imply endorsement by the Bureau of Mines unless otherwise stated.

OVERVIEW OF THE RESPIRABLE DUST RESEARCH PROGRAM

by

John A. Breslin[1]

The Respirable Dust Research Program of the Bureau of Mines originated with the Federal Coal Mine Health and Safety Act of 1969. This act established mandatory health and safety standards, including a standard for respirable dust, which is now 2.0 mg/m^3 for the average concentration of respirable dust to which coal miners may be exposed. The act also authorized research "to develop new or improved means and methods of reducing concentrations of respirable dust in the mine atmosphere of active workings of the coal mine." This research is being done by the Bureau of Mines, and some of the results of this work are presented in this report.

Respirable coal mine dust is the portion of the airborne dust that penetrates to the deepest parts of the lung where it accumulates and eventually may cause coal worker's pneumoconiosis. This is the medical name for the disease that is commonly called "black lung disease." The most recent studies by the National Institute for Occupational Safety and Health (NIOSH) show that the prevalence of pneumoconiosis among working underground coal miners is between 10 and 15 percent. About 173,000 miners and 333,000 survivors and dependents are receiving black lung compensation from the Federal Government. The cost of this compensation to the taxpayers is about $1 billion per year. Thus, the cost of excessive respirable dust in mines is very high, both in human and in economic terms.

The objective of the Bureau's Respirable Dust Research Program is to develop new and improved technology to protect miners against respirable dust. The Bureau's mission concerns the control and measurement of coal mine dust. We do not do any medical studies since these are the responsibility of NIOSH. The Bureau also no longer enforces the coal mine health and safety regulations. This has been the responsibility of the Mining Enforcement and Safety Administration (MESA) since 1973. However, the Bureau does conduct research to assist MESA in the development and enforcement of health and safety standards.

There is a general consensus that dust levels in coal mines are much lower now than they were in 1969. This is primarily due to the improved methods of face ventilation now being used. However, there are still major problems in controlling dust in some mining operations, expecially in (1) low coal mines which use auger-type mining machines, (2) mines using boring-type machines, and (3) on longwall faces. For this reason, the Bureau has put great emphasis on solving the dust problems involved with these mining operations. There is even a need to improve dust control technology for mining operations that are in compliance with the respirable dust standard because of (1) the difficulty involved with some of the present dust control methods,

[1]Staff engineer, Office of the Assistant Director--Mining, Bureau of Mines, Washington, D.C.

(2) possible conflict between some methods used to control respirable dust and methods to control methane, and (3) increased production of coal in the future to meet the Nation's energy requirements with a possible corresponding increase in production of respirable dust.

The current level of funding for respirable dust research for coal mines by the Bureau of Mines is $1.8 million per year. About 40 percent of this is spent on in-house research projects; the rest is for research and development contracts and grants. The in-house research and the monitoring of the outside contracts is done at the Pittsburgh Mining and Safety Research Center and the Twin Cities Mining Research Center. The work at Twin Cities is primarily concerned with minimizing the formation of airborne dust by the optimization of mining-machine cutting parameters or by the use of "wet-head" mining machines. The rest of the research on dust measurement and control is either done at or monitored by the Pittsburgh facility.

Some of the dust control technology that will be covered at this seminar includes (1) optimization of machine cutting parameters, (2) face ventilation, (3) dust collectors, (4) water infusion of the coalbed, (5) wet-head mining machines, (6) improved water spray systems, and (7) personal protection devices for the miners. A number of possible dust control methods investigated by the Bureau will not be discussed at this seminar either because they do not now appear to be practical for use in coal mines or because their application in mines is still some years in the future. These include the use of electrostatics, sonic agglomeration for dust collection, and water-jet cutting of coal. Electrostatic dust collection does not seem practical for coal mines because of possible safety problems such as methane ignition. The use of steam for dust collection did not prove to be much more effective than the effective amount of water sprays in laboratory tests conducted by the Bureau. A study of sonic agglomeration as a dust collection mechanism showed it to be impractical for application in coal mines because of the high sound levels required. Under the Bureau's Respirable Dust Program, research was funded on water-jet cutting of coal which should produce less airborne dust than current methods of coal cutting. This research is continuing with funding under the Bureau's Advancing Mining Technology Program but its practical application in coal mines is still in the future.

The Bureau of Mines is investigating what we believe is nearly every promising approach for improving dust control technology for coal mines. Some of the possible control techniques that looked very promising in 1969 have been thoroughly investigated and been shown to be impractical for use in coal mines. Some of the other dust control techniques are still under active development by the Bureau. Much of the work done or funded by the Bureau of Mines has resulted in improved dust control technology that can be used in coal mines today. This technology will be discussed by the speakers at this seminar.

MESA'S RESPIRABLE DUST ENFORCEMENT PROGRAM

by

Joseph Lamonica[1]

In May 1976, the Mining Enforcement and Safety Administration (MESA) and the National Institute of Occupational Safety and Health (NIOSH) sent to appropriate government agencies and representatives of coal mine operators and miners, a working draft of possible revisions of the Mandatory Health Standards--Underground Coal Mines (30 CFR 70). The purpose of this presentation is to discuss the reasons for proposing changes at this time and to discuss the respirable dust portion of that draft.

The present respirable dust regulations have been in effect for about 6 years, and few can argue that the respirable dust conditions in our Nation's coal mines have not improved during this time. However, we must admit that (1) compliance with the 2.0-mg/m^3 standard is not being met in all places at all times, (2) our statistics are based on data that has a level of uncertainty that says our results are not absolute, (3) our determinations of dust concentrations are always after the fact compounded by a work place that is always moving and ever changing, and (4) the present program has inefficiencies that result in samples being taken unnecessarily causing a burden on the coal miner and a needless expense to the coal operator (table 1).

TABLE 1. - Underground sections cited for excessive respirable dust in 1975

Times cited	Number of sections	Percentage
0	3,040	68.9
1	899	20.3
2	317	7.2
3	109	2.5
4	32	.7
5	13	.3
6	4	.1
7 or more	0	.0
Total	4,414	100.0

With 6 years of experience with the present program and a data bank containing the results of over 2 million samples, we feel that we are ready to make some improvements. These improvements will not solve all of our problems, but they will be a step toward that end.

The present regulations result in approximately 500,000 respirable dust samples per year being submitted to MESA. A preliminary study conducted by MESA determined that the cost to the industry per sample averaged around $18

[1]Chief, Division of Health, Mining Enforcement and Safety Administration, Arlington, Va.

with wide variations. If this cost figure is correct, the expenditure to the industry for taking dust samples would be approximately $9 million. The proposed changes would reduce the number of samples per year by one-half, assuming all things being equal.

MESA receives 500 to 900 unsigned data cards per month. Our investigations show that the overwhelming reason that the miners refused to sign was because they fear that a future claim for black lung benefits would be jeopardized. The proposed changes depersonalize the program. Dust samples would be tied to occupations and areas rather than to individuals.

The proposed changes seek to improve the quality of samples that are required to be taken by the operator. This will be accomplished through stricter training requirements and closer monitoring when samples are taken.

We have received comments on the changes under consideration from other government agencies, the United Mine Workers of America, and a multitude of coal operators either directly or through their affiliation, the Bituminous Coal Operator's Association. These comments have received due consideration and some changes have already been made. We are presently awaiting a detailed comment paper from a coal operator affiliation, after which a final draft will be prepared for proposed rulemaking publication.

Let us now examine some of the major changes being considered.

Section 70.101 (Respirable Dust Standard When Quartz Is Present).--The U.S. Department of Health, Education, and Welfare has proposed that the average concentration of respirable dust in the mine atmosphere of active workings be controlled so that the average concentration of quartz is maintained at or below 0.07 mg/m^3 of air as measured by the MRE dust sampler. This represents a more stringent standard than that presently in effect. Justification for this lower standard is contained in HEW publication 75-120 entitled "Occupational Exposure to Crystalline Silica."

Section 70.202 (Sampling, Qualified Person).--Present regulations allow sampling to be done by, or as directed by, a qualified person.

It is proposed that this procedure be changed to the extent that dust sampling required by this Part 70 shall be done by a qualified person. The qualified person shall be required to have at least 12 months of experience working underground in a coal mine during the preceding 3 years.

The qualified person shall be able to pass a written examination conducted by MESA, and is required to be requalified at least every 2 years.

Provisions for temporary qualifications are also provided for.

The qualified person will be responsible for the accuracy of the sample, and will be required to sign the data card; the miner will no longer be required to sign the data card.

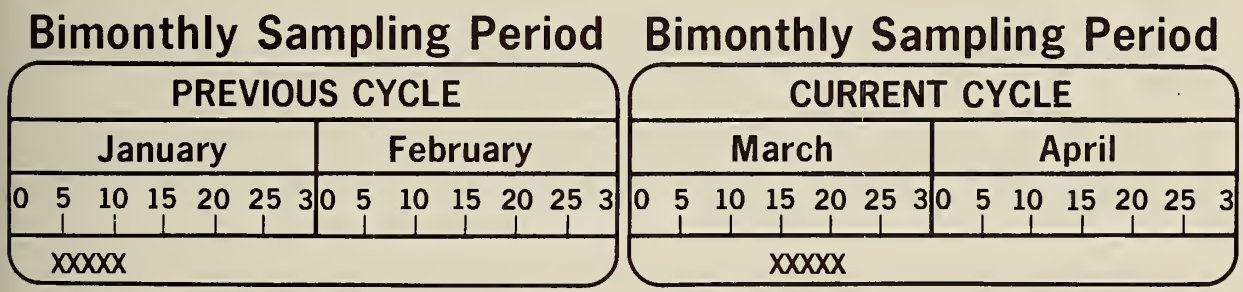
Section 70.204 (Approved sampling devices; maintenance requirements). A program for maintenance of respirable dust sampling pumps shall be established.

Maintenance requirements proposed include a maintenance program, records of all repairs and tests, identifying sampling pumps and legible exterior markings, a record of the hours of use, and examinations of sampling devices by a qualified person before each shift.

Sampling devices shall be examined each shift by a qualified person between the first and second hours and during the last hour of operation to assure that the pump is operating properly.

Section 70.208 (Establishment of bimonthly series)--The proposed regulation eliminates the taking of intake samples. High-risk samples will be required from each mechanized mining unit during fixed calendar periods of 2-month duration referred to as bimonthly sampling periods. MESA will require 5 samples to make a determination of compliance of noncompliance, rather than the 10 samples presently required.

The two primary provisions of section 70.208 are as follows: Section 70.208(a)--Five samples shall be taken and submitted during the first month of the bimonthly sampling period; and section 70.208(d)--Five valid samples shall be taken and submitted during the bimonthly sampling period.



1. 70.208(a) requires 5 samples to be taken and transmitted from from the high-risk occupation in each mechanized mining unit during the first month of each bimonthly sampling period.

2. The results of each sampling series indicate compliance with the 2.0 mg/m³ standard.

3. Since the example indicated none of the samples are void, the requirements for high-risk sampling have been completed.

X-Portal to portal respirable dust sample

FIGURE 1. - High-risk sampling.

The operator will be notified of any samples that are voided the first month and will have an opportunity to replace these samples during the second month.

Each cycle must stand on its own, and no catchup of delinquent samples will be permitted.

Failure to comply with either legal requirement of bimonthly sampling will result in a 104(b) Advisory of Violation from the computer 7 days after the first or second month of the bimonthly period. If MESA determines that the operator could have complied with the legal requirement but failed to do so, a "notice of violation" will be issued, the notice will be terminated, and the operator will be penalized. Since the bimonthly period has progressed to the next current period, samples will not be required for makeup, and the computer program progresses normally to the next bimonthly period, not being affected or influenced by any violation for insufficient samples.

Samples whose concentration exceed the standard of 2.0 mg/m^3 will result in a 104(i) Notice of Violation and the suspension of sampling requirements during bimonthly periods until the Notice has been terminated.

The new program as proposed will require a new computer system, which includes a terminal in each district/subdistrict office and the capability of processing samples required by a notice of violation in the subdistrict office.

Section 70.212, which presently requires immediate transmission of samples, will require samples to be transmitted within 24 hours.

The determinations of "normal production shift" will be based on production reported by the operator during the sampling shifts that constitute the previous bimonthly sampling period.

Section 70.209 is a proposed regulation that describes the area samples that are designed to (1) replace individual samples and (2) avoid or eliminate the problems of miners refusing to wear the sampling pump and sign the mine data card.

One sample will be required from each designated nonface area of the mine during bimonthly sampling periods, which are staggered with respect to the high-risk periods. Similar legal requirements apply to area samples as with high-risk samples with the exception that when an area sample exceeds 2.0 mg/m^3, the operator will be requested to submit five additional samples to determine compliance or noncompliance with the respirable dust standard. A 104(i) Notice of Violation may be issued to designate nonface areas of the mine, and the level of respirable dust in these areas must be reduced and controlled, and samples must be submitted by the operator each production shift until the notice is abated.

Section 70.214 revises the present procedure of assigning four-digit identification numbers to sections. Under the proposed regulations, an

identification number will be assigned to each mechanized mining unit or each unit of production equipment and will remain permanently with that unit of equipment during the life of the unit, regardless of where the unit moves to in the mine.

This paper has attempted to briefly explain (1) the reasons for proposing revisions of the existing respirable dust regulations and (2) those changes that are most significant. These changes are designed to effect more efficient regulations and to increase the creditability of the sampling results. MESA changed its inspection procedures for dust sampling in underground coal mines last September. This was the first step toward increasing the efficiency and effectiveness of the respirable dust program. The MESA program is designed to establish engineering parameters for controlling dust through evaluation of the dust control plan.

Dramatic program changes will result from Bureau of Mines research. Solutions to the respirable dust problems of today through Bureau of Mines research will necessitate keeping the regulations in step with the new technology, some of which is presented in this report.

For those not familiar with the regulatory process, let me explain very briefly where we are with respect to the respirable dust regulations. The review of the working draft is considered the consultative step in the regulatory process. We are closely reviewing the comments that have been made by all interested parties. After taking into consideration these comments, a final draft will be prepared and a decision will be made by both the Department of HEW and Interior to propose the draft, in whole or in part, as rulemaking by publication in the Federal Register. At that time all interested parties will have another opportunity for comment and also an opportunity to request a public hearing to air their objections. Then, based on the findings of the Secretary of HEW with regards to the comments and any public hearings, direction may be given to promulgate mandatory standards or publish reasons for not promulgating a standard.

RESPIRABLE DUST MEASUREMENT

by

John A. Breslin[1]

ABSTRACT

A review is presented of the instruments that can be used or are under development for use in coal mines to measure concentrations of respirable dust. Both the advantages and limitations of the instruments are discussed. The review includes the work being done by the Bureau of Mines to develop instrumentation and to improve techniques for dust measurements in mines for both determining compliance with dust standards and evaluating the effectiveness of dust control techniques.

INTRODUCTION

Three main categories of instruments being used in coal mines will be discussed in this review. These are (1) gravimetric dust samplers, (2) short-term dust monitors, and (3) instruments for particle size measurements. The overwhelming majority of mine dust measurements are made to determine compliance with coal mine dust standards and also to determine the effectiveness of dust control techniques in mines. Short-term dust monitors measure dust concentrations over a short time interval and give an immediate readout in the mine. They are especially useful for locating dust sources and for evaluating dust-control techniques. There are also instruments available that are being used by the Bureau of Mines and Bureau contractors to sample dust in mines and later determine not only the dust concentration, but also the particle size distribution.

GRAVIMETRIC DUST SAMPLERS

The Federal Coal Mine Health and Safety Act of 1969 established a respirable dust standard for the active workings of coal mines, which is now 2.0 mg/m^3 for the average concentration during each shift. Dust concentrations are to be measured with an MRE instrument or with another approved device that measures equivalent concentrations.

The MRE instrument (3)[2] is the MRE gravimetric dust sampler type 113A, which was developed by the Mining Research Establishment of the British National Coal Board during the 1960's. The instrument is termed "gravimetric" because the mass of respirable dust is determined by weighing the amount of dust collected on a filter. The sampler (fig. 1) consists of a size selector, a filter holder and an electrically driven air pump. The size selector is a

[1]Staff engineer, Office of Assistant Director--Mining, Bureau of Mines, Washington, D.C.

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

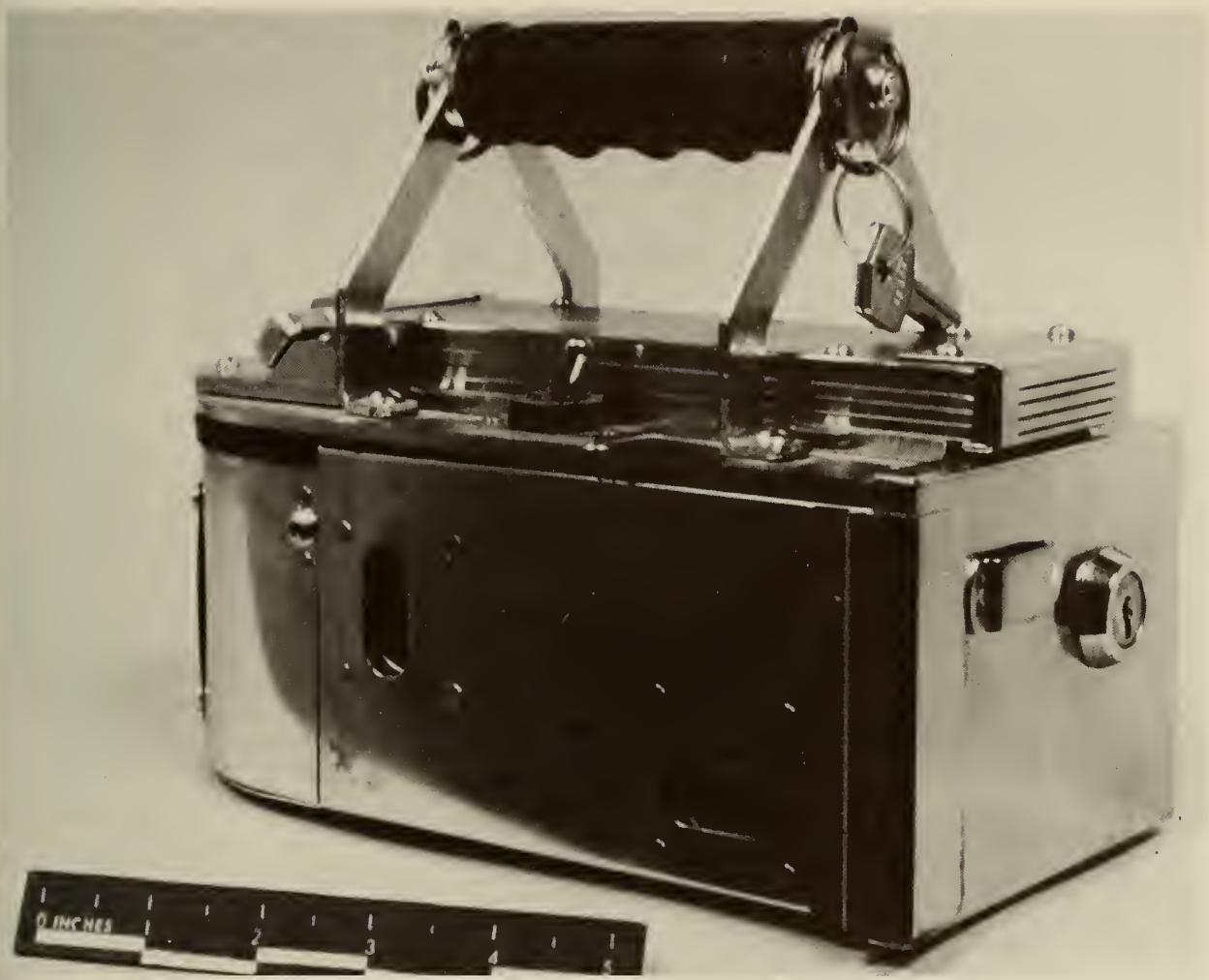


FIGURE 1. - MRE gravimetric respirable dust sampler.

four-channel horizontal elutriator mounted on top of the instrument; the selector removes the larger airborne dust particles so that only respirable dust is deposited on the filter. The instrument, including the elutriator, must be operated in a horizontal position. The horizontal elutriator removes 50 percent of those particles with an aerodynamic diameter of 5 micrometers and all particles with an aerodynamic diameter greater than 7.1 micrometers. The weight of the MRE instrument is about 9 pounds. Because it is larger and more expensive than the personal sampler, MRE instrument is not used very much in U.S. coal mines.

The most commonly used dust samplers in U.S. mines are the MSA-Monitaire and Bendix Micronair personal dust samplers shown in figure 2. The personal sampler (9) consists of an air pump, filter cassette, and a small nylon cyclone that acts as a size selector to remove nonrespirable dust aprticles.

The personal sampler is operated at 2.0 1/min for coal mine dust measurements. The concentration measurements with the personal sampler are

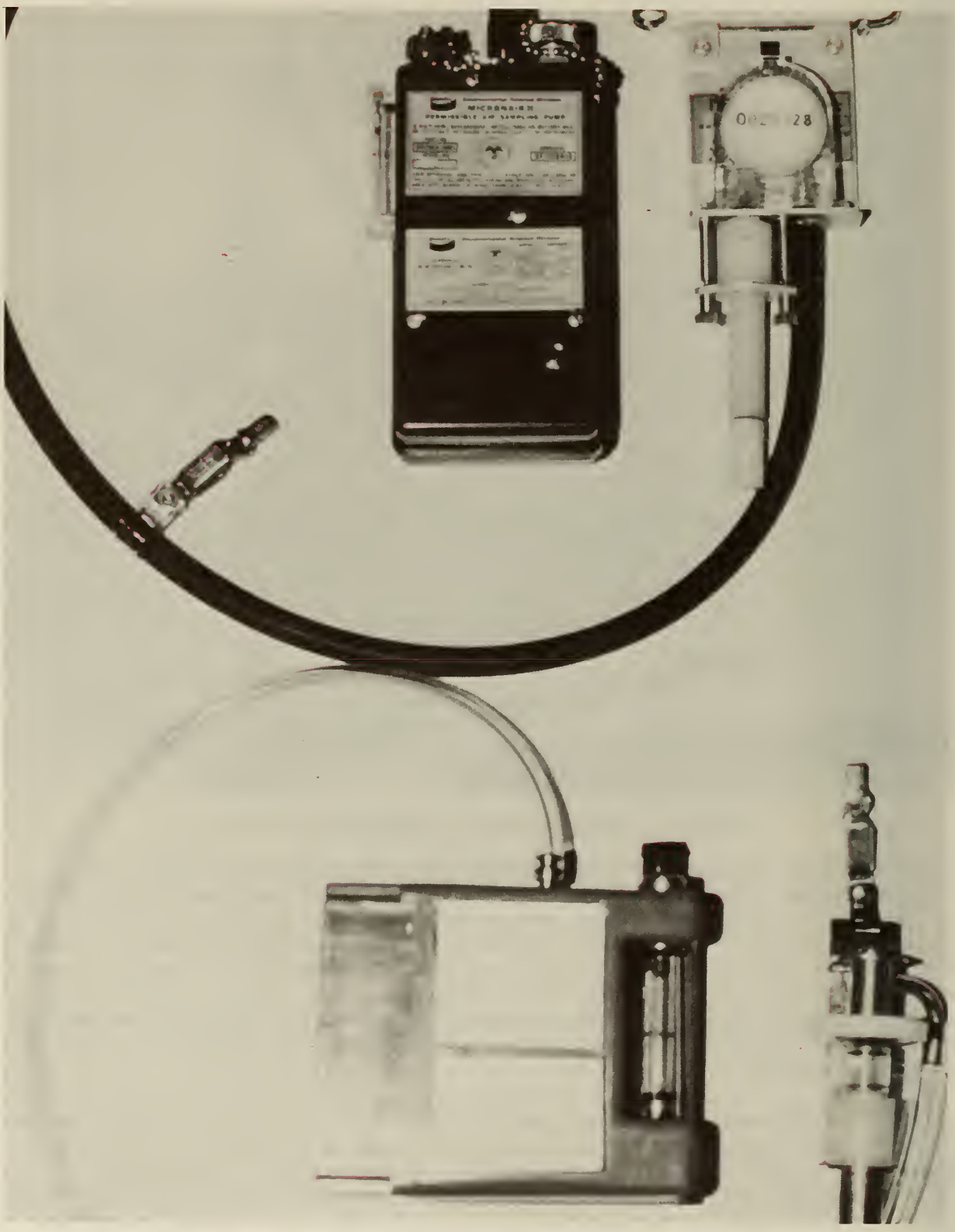


FIGURE 2. - Bendix (top) and MESA (bottom) personal respirable dust samplers.

multiplied by a conversion factor of 1.38 to determine the equivalent MRE concentration. Unlike the MRE, the personal samplers are small enough to be worn by miners for better measurements of their personal exposure to respirable dust. Under normal conditions in coal mines, the personal samplers are operated for a full 8-hour shift.

The personal samplers are the instruments most commonly used by both mine operators and inspectors to determine whether coal mines are in compliance with dust standards. The samplers have been criticized in the past few years and, in particular, the accuracy of the dust measurements has been questioned. The National Bureau of Standards recently completed a study of the accuracy of coal mine dust measurements. The report (8) mentioned the following factors as possibly affecting the accuracy of dust measurements with personal samplers:

1. Airflow is difficult to adjust and maintain during use.

2. The actual volume of air sampled is not indicated by the instrument.

3. Simultaneous inversion and impact of the sampling head could contaminate the dust sample with nonrespirable particles.

4. The sampling head is difficult to assemble and could be knocked out of alinement by physical impact.

5. The sample could be altered without detection.

The Bureau of Mines has investigated the precision of dust measurements with personal samplers over the past 2 years. Dust measurements have been made in coal and noncoal mines and processing mills with personal samplers operated side by side in packages (fig. 3). Data collected by Bureau contractors both in the laboratory and in coal mines has also been evaluated.

The main results of these studies follow:

1. The coefficient of variation of measurements with the personal sampler in the laboratory is about 4 percent.

2. The coefficient of variation for dust measurements in coal mines with personal samplers can range from 7 percent to greater than 50 percent.

3. The true dust concentrations in coal mines vary from shift to shift with a coefficient of variation typically between 30 and 70 percent.

The laboratory measurements show that the personal sampler itself is a reasonably precise instrument when operated according to the proper procedures. The reasons for the greater variation in the dust measurements made in coal mines are not completely understood and are the subject of some controversy. The increased variation is probably due partly to the difficulty in operating the dust samplers under mine conditions and possibly also partly due to real variations in dust concentration between sampler locations.

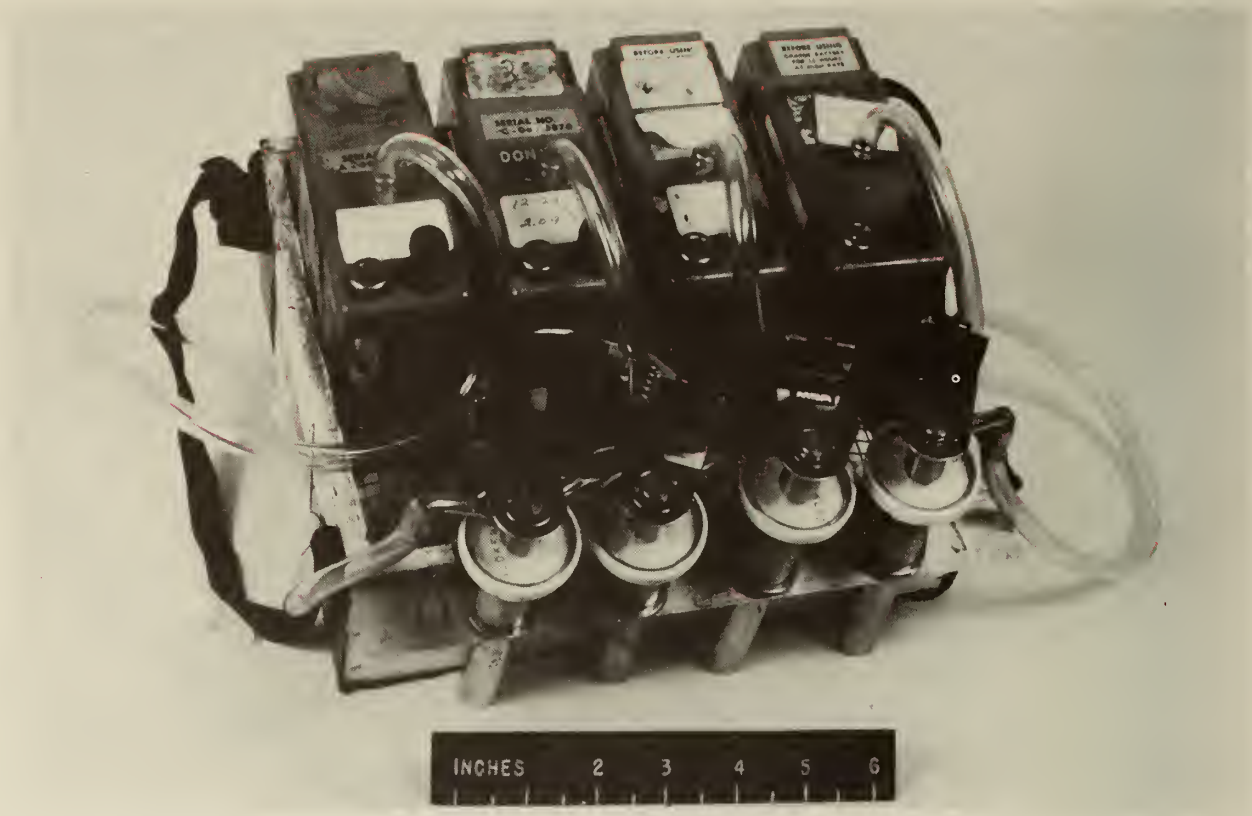


FIGURE 3. - Sampler packages used to determine precision of dust measurement.

After reviewing all the available data on coal mine dust measurements, the National Bureau of Standards (8) concluded the following:

> "The uncertainty to be expected in the normal program operations, i.e. when the miners and mine operators perform and supervise the sampling and when the weighings are made in the normal manner, is estimated to be as large as 31 percent of 0.63 mg/m^3."

This uncertainty of 31 percent (at a mean of 2.0 mg/m^3) is the coefficient of variation for a single dust measurement. The uncertainty owing to measurement error can be reduced by taking an average of many dust measurements.

Even if the dust measurement were extremely precise, it would still be difficult to obtain a good estimate of an average dust concentration for a coal mine section. This is because of the large variation (30 to 70 percent) that usually occurs in the true dust concentrations at any location in a mine from shift to shift. Differences in dust concentration occur because of variations in the amount of coal mined, changes in the coal from place to place, and variations in the ventilation and other dust-control parameters such as water sprays. Under normal production conditions, the dust concentration near a continuous-mining machine operator in a mine can have a coefficient of variation of 70 percent. The variation is usually smaller for

dust concentrations in return airways, but even then it is usually greater than 30 percent.

This variation in dust concentrations from shift to shift make it very difficult to determine the real effectiveness of dust control techniques in coal mines when using personal samplers for dust measurements. Figure 4 shows the number of tests required under each condition to be 90-percent confident that there is a reduction when using a new dust-control technique. For example, if a 20-percent reduction were observed under a normal production situation where the coefficient of variation is about 70 percent, then about 42 measurements are required before and 42 after the dust-control technique is introduced. Since a full shift is normally required for a single personal-sampler measurement, an impractically large number of 84 shifts would be required to achieve 90-percent confidence that the new technique is effective. The number of shifts required can be greatly reduced if the observed dust reduction is much larger, or if the coefficient of variation of the measurements is reduced by maintaining as constant as possible the parameters that effect dust levels. A dust reduction of 40 percent or greater is not too difficult to demonstrate after about 20 shifts. However, one should be very

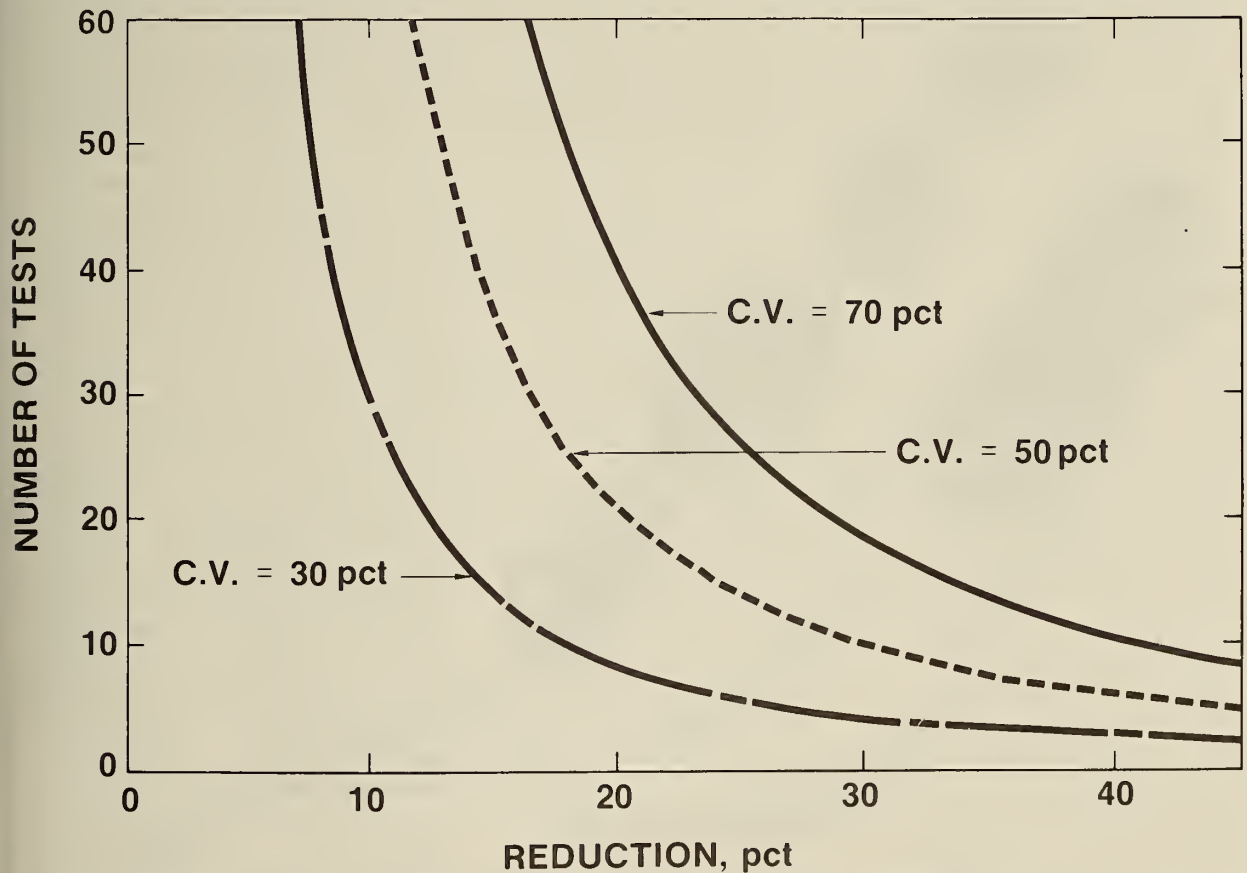


FIGURE 4. - Number of tests at each condition required to detect a reduction in dust levels with 90-percent confidence. (C.V. is the coefficient of variation of dust concentrations.)

skeptical about claims for the effectiveness of any control technique that has been tested for only a few shifts.

SHORT-TERM DUST MONITORS

The problem of evaluating dust-control techniques in coal mines can be simplified by using an instrument that can measure dust concentrations after a much shorter time interval than that required by the personal sampler. Instruments are available that can measure the dust concentration after 1 minute or less and also give an immediate readout in the mine. These instruments are useful for locating and determining the magnitude of dust sources in mines and are especially useful for evaluating some dust-control methods such as dust collectors, which can be quickly and repeatedly turned on and off in a mine. With a short-term dust monitor, many dust measurements can be made during one shift, and thus it is possible to determine the effectiveness of the collector in one shift instead of the dozens required using personal samplers.

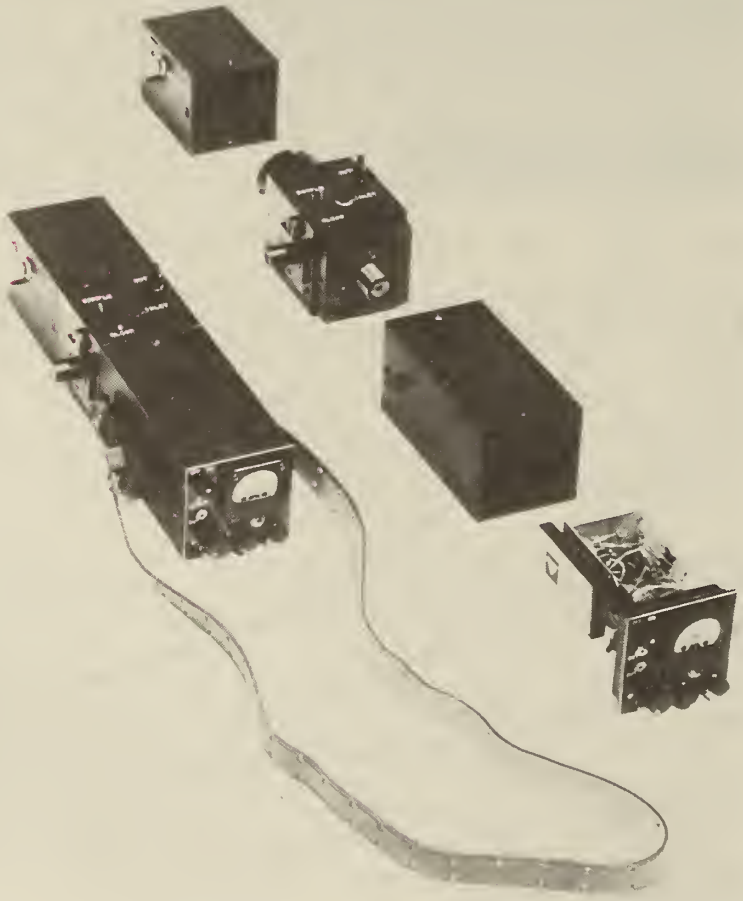


FIGURE 5. - SRI light-scattering dust monitor.

Instruments that use the principle of light scattering to measure dust concentrations have been available for many years. However, none were suitable for use in coal mines. Under a Bureau of Mines contract, Stanford Research Institute developed an intrinsically safe, portable, light-scattering dust monitor for use in coal mines (4). This SRI dust monitor (fig. 5) is used in conjunction with an MSA personal sampler. It consists of three sections. The back section contains an incandescent bulb, which is powered by the battery of the MSA pump. The middle section contains the optics and a chamber through which respirable dust is drawn by the MSA pump. Light scattered from the dust in the forward direction is detected by a photodiode in the front section of the instrument. The signal from the photodiode is amplified and displayed on a meter on

the front panel. The meter reading is proportional to the concentration of respirable dust that enters the instrument.

The SRI dust monitor is about 3 inches high by 3 inches wide by 14 inches long and weighs 6.9 pounds exclusive of the MSA sampler. It is a continuous monitor; that is, the meter continuously responds to changes in dust concentration. The response time for the instrument to reach 90 percent of its final reading is 6 seconds after any sudden change in dust concentration.

The response of any light-scattering dust monitor depends on the index of refraction and size distribution of the dust measured. Thus, the SRI dust monitor cannot read out directly a mass concentration (mg/m^3) of dust, although it can be calibrated to give an approximate mass concentration to within ±50 percent in coal mines. It is of great value in conducting mine surveys to determine the relative magnitude of dust sources, and for any other purposes in coal mines where differences in dust levels rather than absolute mass concentration measurements are needed.

Figure 6 shows the response of an SRI dust monitor to mass concentration of respirable coal dust measured in a Bureau of Mines laboratory. The data show that as long as the size distribution and type of dust is kept the same, the response of the SRI monitor is linear up to at least 40 mg/m^3. Theoretically, the response should be linear up to hundreds of milligrams per cubic meter, which is well beyond the range required for dust measurements in coal mines.

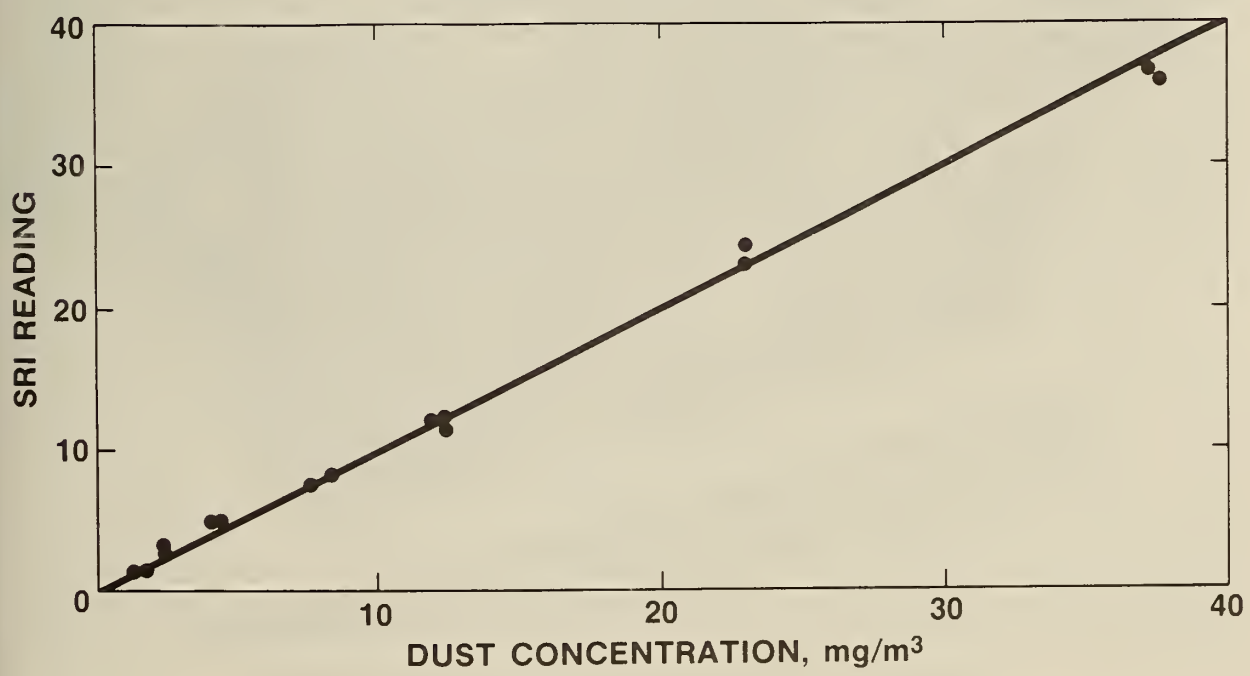


FIGURE 6. - SRI reading versus gravimetric dust concentration.

Another instrument used for dust measurements in coal mines is the GCA model RDM-101 respirable dust monitor (6) shown in figure 7. Respirable dust is collected inside this instrument by impaction on a thin, grease-coated plastic disk. The mass of dust collected over a short time period (for example, 1 minute) is measured by the change in attentuation of beta radiation caused by the buildup of dust on the impaction disk. The instrument weighs 6.6 pounds and is intrinsically safe for use in coal mines. It is battery powered and completely self-contained. At dust concentrations normally encountered in coal mines, about 1 minute is required for a measurement. At the end of the 1-minute sampling period, the average dust concentration over that period is read out on a digital display.

The great advantage of this instrument over light-scattering dust monitors is that, within certain limits, the instrument measures the mass concentration independent of the type of dust and particle size distribution.

FIGURE 7. - GCA respirable dust monitor model RDM-101.

Since impaction is used to collect the dust, only dust particles larger than about 0.7 micrometer in diameter will be collected and measured accurately. Normally, most of the mass of respirable dust in coal mines will be in particles larger than this size.

Laboratory tests by the Bureau of Mines have shown the GCA RDM-101 dust monitor to give low measurements at high coal dust concentrations. When this defect was brought to the attention of GCA, the company changed the recommended coating material for the impaction disks; this has partially corrected the problem. The University of Minnesota, under a Bureau of Mines contract, has recently completed an evaluation of the GCA RDM-101 (7). The university investigators also found that the response tended to fall off at higher concentrations, although the newer instruments using the revised coating gave reasonably accurate measurements for respirable coal dust concentrations up to about 10 mg/m^3. The accuracy of the instrument can be improved at high concentrates by using a sampling time shorter than 1 minute.

GCA Corp., under a Bureau of Mines contract, developed a respirable-dust-recording mass monitor (5). This instrument uses the same particle-impaction and beta-attenuation system as the RDM-101. In addition, the instrument will automatically take up to 450 1-minute measurements of respirable dust and print the individual mass concentration measurements on paper tape. This instrument allows automatic unattended operation for up to 8 hours on battery power.

GCA has now produced a modified version of the respirable-dust-recording mass monitor called the GCA RDM-301 (fig. 8). It is 18 inches long by 13 inches wide by 11 inches high and weighs 42 pounds, including the battery. It is intrinsically safe for mine use. This instrument has the same disadvanatge as the RDM-101 in that the accuracy of coal dust measurements is questionable at high dust concentrations. However, it does have application particularly for research purposes where a quasi-continuous record of mass concentration of dust is needed. This type of instrument may eventually evolve into a dust monitor that could be used in the face area of a coal mine to warn mine personnel that dust levels are too high. The Bureau of Mines is developing this type of respirable dust instrument.

FIGURE 8. - GCA respirable dust monitor model RDM-301.

PARTICLE SIZE MEASUREMENT

Prior to the late 1960's, the midget impinger was the most commonly used instrument for measuring airborne dust in mines. It can still be useful for short-term dust-concentration measurements when it is not necessary to have an immediate readout in the mine. The Bureau of Mines uses the Coulter Counter (1) to measure the dust concentration and particle size distribution of samples collected with midget impingers. The Coulter Counter can also be used to count and size particles collected on a suitable filter (for example, the Nuclepore) if all the particles can be washed from the filter with alcohol without significant deterioration of the filter.

The Coulter Counter counts and sizes dust particles according to the volume diameter of the dust particles. It can be used to size particles slightly below 1 micrometer in diameter. The major disadvantage of measuring coal mine dust size distribution with the Coulter Counter is that the dust must be suspended in a liquid, usually isopropyl alcohol. Any coal dust particles existing as part of agglomerates while airborne will separate in the

alcohol. Thus, the particle sizes measured with the Coulter Counter may be somewhat smaller than the particle sizes of the original airborne dust.

The Bureau of Mines has also made use of a scanning electron microscope (SEM) for measuring the particle size of coal mine dust (2). The SEM can produce useful photographs of dust particles less than 0.1 micrometer across. Examination of dust samples with the SEM shows that agglomerates of two or three particles are very common in coal mine dust. Larger agglomerates occur but are relatively rare.

IMPROVING MINE DUST MEASUREMENTS

The Bureau of Mines is now involved in or planning various projects to improve the measurement of respirable coal mine dust. The studies of the precision of mine dust measurements will be extended in cooperation with MESA, NIOSH, and the National Bureau of Standards. The purpose of the new study is to determine quantitatively the precision of the dust measurements made with the current sampling equipment by coal miners in underground mines.

Eastern Associated Coal Corp. has recently completed a study of the feasibility of area sampling in the face area of coal mines. Dust measurements from samplers on miners correlated well with measurements from samplers located at fixed points near the miners. The Bureau has also awarded a contract to MSA Research Corp. for a study of area dust sampling at points located outby the face. The advantage of area sampling is that the miner does not have to wear the sampler. It also may allow the eventual use of larger, more accurate and reliable instruments.

Two contracts are already underway for improving the filter cassettes of the personal samplers. Bendix and MSA have Bureau contracts to develop tamper-proof cassettes. The contracts call for filter cassettes with the following features:

1. One-way flow valves to prevent the filter from being back-flushed with air.

2. A case designed to prevent the cassette from being opened and reassembled.

3. Traps to prevent dust from being shaken from the filters.

Both contractors have already delivered prototype cassettes, but the improved features may add to the cost of the cassettes if they are adopted. The advantages of the improved features will be balanced against any increased cost of the cassettes before the new cassettes would be required by any new regulations. The Bureau is also considering a similar project for improving the sampling pumps.

The long-range goal of the Bureau in the area of coal mine dust measurement is the development of a dust monitor that could be mounted on face machines in coal mines and would continuously monitor respirable dust

concentrations during every shift. The respirable dust recording mass monitor developed for the Bureau by GCA is one possible type of instrument for this purpose. The Bureau has recently awarded contracts to GCA and Bendix for developing machine-mounted dust monitors using the principle of beta attenuation to measure the mass of dust collected on a filter. A machine-mounted dust monitor for regular use in coal mines is probably at least 15 years away. However, once it is available, it will be possible to automatically monitor respirable dust levels in the face areas of coal mines. If dust levels become excessive, an alarm can be set off so that the situation can be corrected immediately.

CONCLUSIONS

The state-of-art of coal mine dust measurements has been reviewed. There is no perfect instrument for the measurement of respirable dust in mines. The personal samplers are the most commonly used and are the best available instruments for measuring the exposure of miners to respirable dust. Short-term dust monitors are available that give a readout of dust concentration in the mine, which can be very useful for locating dust sources and evaluating dust control techniques. All the available instruments have some limitations of which the user should be aware.

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REDUCED GENERATION OF AIRBORNE RESPIRABLE DUST THROUGH DEEP-CUTTING CONTINUOUS MINERS

by

Sigmund Black[1] and Robert Schmidt[2]

Recognizing the danger of health and safety hazards in coal mines, Congress passed the Federal Coal Mine Health and Safety Act of 1969 to legislate improved standards and working conditions. For its part, the Bureau of Mines assumed the responsibility of assisting the underground mine operators in meeting, and if possible, surpassing the new safety limits through practical improvements in mining machines, methods, and systems. As part of the overall program, considerable effort has been directed toward reducing respirable dust through improvements in ventilation and water sprays as well as methods of cutting, or winning, the coal.

Ingersoll-Rand Research, Inc. (IRRI), participated in a full-scale underground test with a continuous-mining machine to study the relationship of coal cutting to the generation of dust. Without question, it is the fragmentation process that produces the coal dust to which the machine operators are exposed. However, all other section miners are subject to dust due to additional fragmentation and the presence of fines throughout the loading and transporting functions. Thus, any improvement in the cutting process has subsequent benefits to all secondary handling operations.

Concentrating on the cutting machine parameters of revolutions per minute, depth of cut, bit spacing, and bit angle, Ingersoll-Rand has been able to dramatically show the relationship of these factors to airborne dust generation per ton of coal won. The tests were conducted using a specially built full-size continuous-mining machine with precise measuring devices and provisions for rapid changes in the mechanical cutting parameters.

The full-scale tests conducted by IRRI were the logical result of prior laboratory and small-scale field experiments conducted earlier by the Bureau of Mines. In turn, this work had been based on the findings of the British National Coal Board, which indicated that shallow cuts were excessively dusty and inefficient in terms of energy used per unit of coal (watt-hours per ton) removed (2).[3] Based on this finding, the National Coal Board expanded its research to medium depths of bit penetration (up to 2 inches) and various bit speeds. Results of the study showed that there was an optimum bit spacing for each depth of cut tested. This early laboratory study was subsequently confirmed by in-mine tests with chain cutters and longwall shearers (1). The conclusion of the British investigation was that slow moving, widely spaced,

[1]Supervisor of Special Projects, Ingersoll-Rand Research, Inc., Princeton, N.J.
[2]Research supervisor, Underground Mining, Twin Cities Research Center, Bureau of Mines, Twin Cities, Minn.
[3]Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

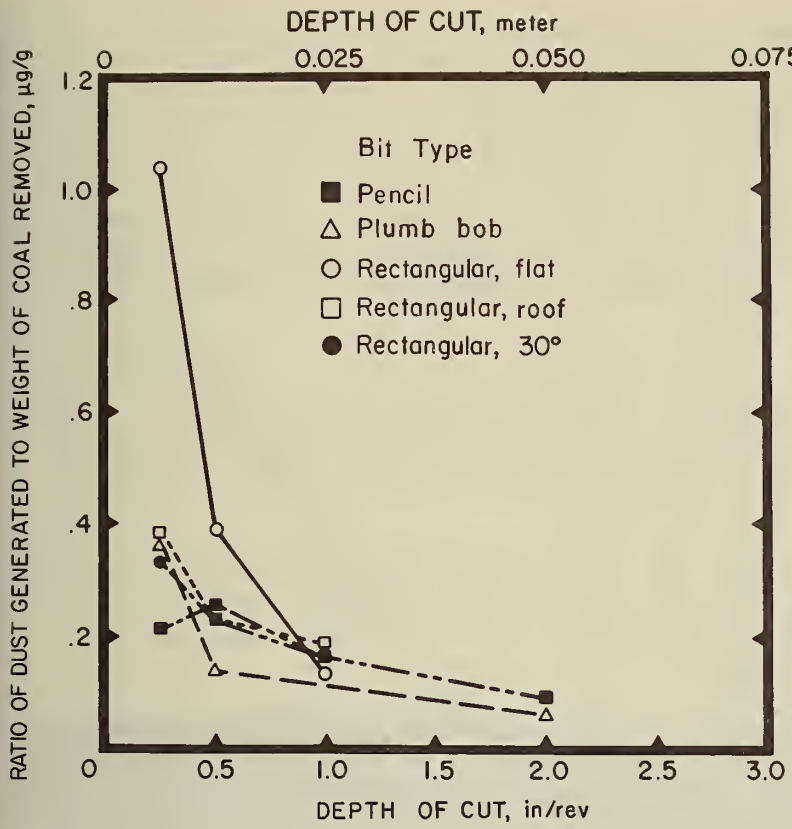

FIGURE 1. - Effect of cut depth on airborne dust generated by first cuts in Illinois coal.

deeper cutting bits achieved optimum cutting efficiency, thus using less energy and producing less dust. However, this work could not be immediately projected to the continuous miners used in the United States because the effect of scaling between the drum of a longwall shearer and the much wider cutting drum of a continuous miner was not known.

The earliest comparative underground test of the deep-cutting principle in the United States was carried out by Ed Warner (4) of the Joy Manufacturing Corp. at a mine working the Illinois No. 6 coal seam. A full-scale Joy 10 CM continuous miner provided four drum speeds between 40 and 80 rev/min, and power consumption and size distribution of the coal product were measured. Unfortunately, meaningful data on respirable dust generated was not collected nor was the depth of cut controlled from test to test. Nevertheless, Warner's results reaffirmed the relationship between power consumption and product size and showed that deep cutting minimized the amount of coal fines produced.

The Bureau of Mines established its own program in 1969 to test and measure the relationship of depth of cut to respirable dust. In the first phase, laboratory bench tests were carried out on different types of coal. During the linear cutting of the coal at several depths with a variety of bit types, the quantity of respirable dust was constantly monitored. Figure 1 summarizes the results of the relationship of respirable dust as a function of the cut depth on a normalized basis of micrograms of dust per gram of coal cut.[4]

[4]Usually dust measurements are given in milligrams per cubic meter of air, but for the purpose of standardizing the quantity of dust for all mines, independent of section airflow and production parameters, the research data described herein are calculated in weight of dust per weight of coal produced; that is, milligrams per ton.

Subsequent Bureau of Mines investigations utilized a scaled-down version of a drum-type continuous miner (3) called a Micro-Miner, which is shown in figure 2. This research machine was equipped with an adjustable servocontrol system to insure precise cutting velocities in both the sump and shear modes at various bit speeds. The information gathered from the tests reconfirmed that the amount of airborne dust generated decreased with increased depth of bit penetration and lowering of bit speeds. Figure 3 graphically shows this decrease in normalized respirable dust produced by deeper penetration into the coal. On the other hand, figure 4 demonstrates the direct effect of lower drum speed on dust generation.

Although the laboratory data were extremely favorable, it was not possible to fully project the findings to a full-size commercial continuous miner. Conclusions based only upon laboratory cutting tests with linear cutters or even the underground Micro-Miner left in doubt the question of the scaling factor between small- and full-size machines.

With this in mind, the Bureau of Mines initiated a full-scale underground test, using a standard-size continuous miner equipped with a battery of precision measuring devices and adjustable cutting features. Eastern Associated Coal Corp. agreed to provide a test section, shuttle car, roof bolter,

FIGURE 2. - Micro-Miner.

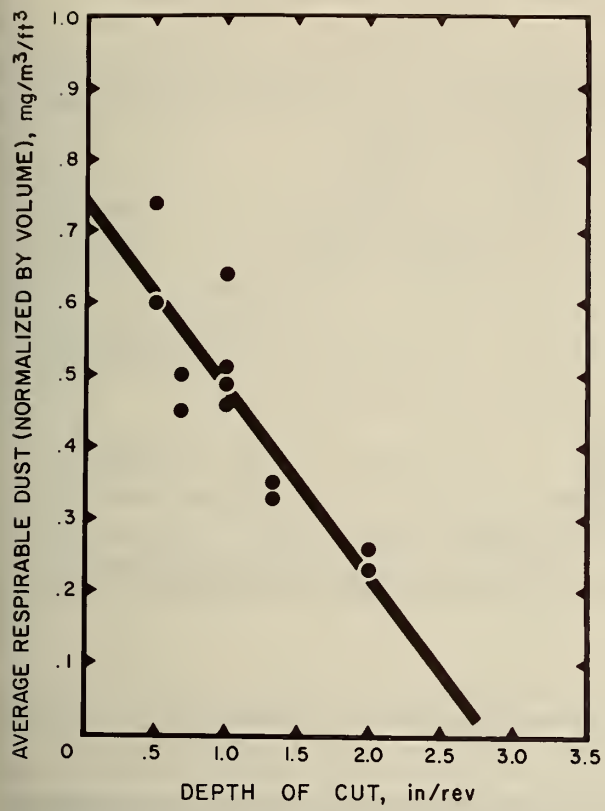

FIGURE 3. - Respirable dust generation versus depth of cut.

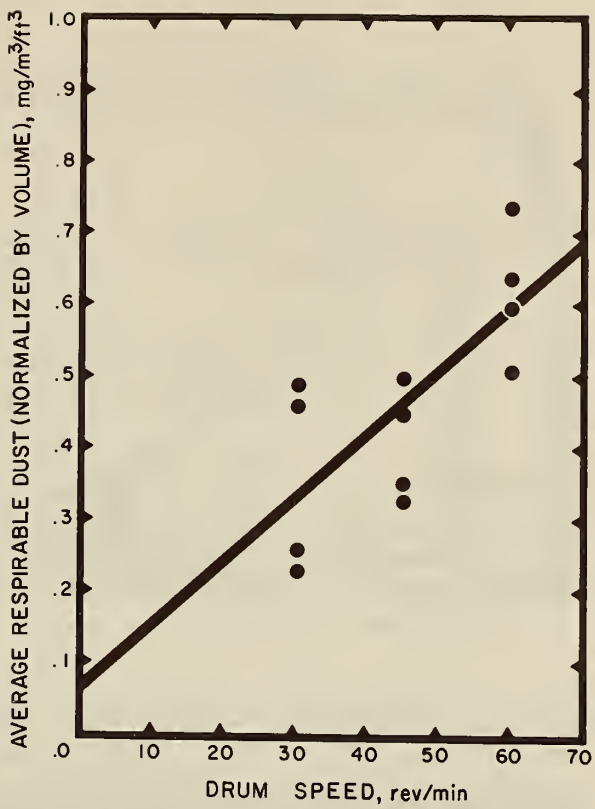

FIGURE 4. - Respirable dust generation versus rotational speed.

transformer, track, and the other necessities needed to work the section, but without requiring any minimum production. Ingersoll-Rand Research, Inc., was awarded a contract for this work in January 1972. Through a subcontract with Lee-Norse Co., a subsidiary of IRRI, a special HH 456 (a modified Lee Norse HH 455) miner was designed for the Bureau of Mines.

Table 1 compares the basic cutting and associated features of a standard Lee Norse 455 miner to those of Bureau of Mines HH 456. As illustrated in figure 5, the unique HH 456 features include a special drum with picks capable of up to a 5-inch depth of cut and bolt-on blocks that enable the bit spacing to be varied from 2 to 12 inches in 2-inch increments. Moreover, two choices of bit angles were possible: 45° and 36-1/2°. Two 225-horsepower (nameplate) head motors provide in excess of 1,000 horsepower pullout torque, while head torque is limited to 116,000 foot-pounds by centrifugal clutches. Three drum speeds of 9, 18, and 51 rev/min are available through modular replacement of gear boxes, thus providing respective bit tip speeds of 101, 210, and 594 ft/min. Also visible in figure 5 is the high-speed belt-gathering head designed to handle over 30 tons/min. Depending on the coal seam, the HH 456, at 51 rev/min and a 5-inch depth of cut on sump, could produce coal at that rate.

TABLE 1. - Comparison of standard HH 455 and HH 456 continuous miners

	HH 455	HH 456
Cutter drum diameter.....inches..	38-3/4	44-1/2
Cutter drum speed.....rev/min..	55	9, 18, and 51
Cutter drum motor.....horsepower..	2 to 150	2 to 225
Cutter drum width.....feet..	10-1/3	10-1/3
Machine weight.....pounds..	97,000	105,000
Gathering head.....	Dual arm	Belt
Auto sump/shear.....	No	Yes

By incorporating sump and shear feed jacks, the velocities of sump and shear are set and are held constant. Constant forces are insured through the inclusion of an adjustable volume, preset positive-displacement pump.

Another specialized feature incorporated on the HH 456 is an automatic control system, designed to perform two complete sump and shear cycles without operator assistance over a wide range of sump/shear velocities. For instance, tests were typically run with two cycles, with sump depths ranging from 16 to 18 inches and with the associated shear travel distance to completely mine the 6-1/2-foot coal seam.

As shown in the plan view, (fig. 6), the miner is located at the face prior to conducting a test cycle. For any combination of parameters of drum speed, depth of bit cut, bit spacing, or bit angle, each test consisted of

FIGURE 5. - HH 456 continuous miner.

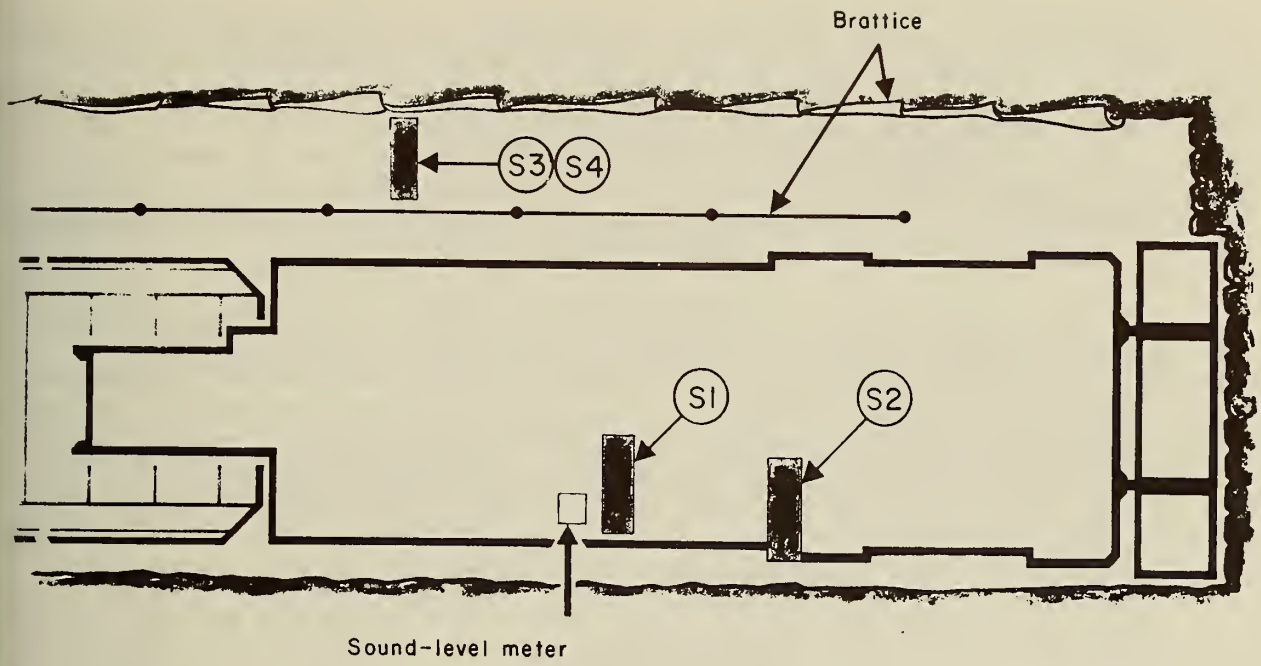

FIGURE 6. - Dust-sampling stations (top view of test section—pretest).

two sump and shear operations and produced approximately 6-1/2 tons of coal. Moreover, measurements of the airborne dust generated were collected at designated locations and at a standardized airflow of 4,000 cu ft/min at the face.

Dust sampling stations are shown in figure 6. The critical station 1 location, just in front of the operator's cab, measures the dust to which the operator is normally subjected. Station 2 is set as near the working face as possible. The key measurements are taken at stations 3 and 4, behind the brattice in the air return because they monitor the true amount of respirable dust produced for each ton of coal mined.

To provide a simple means of analyzing the respirable dust in terms of particle size distribution, the airborne dust was collected by an air sampling pump and in an alcohol solution (midget impinger) rather than on filter paper. Subsequently, the samples were taken to a surface trailer near the mine entrance where they were analyzed using techniques developed by the Bureau of Mines and MESA in earlier programs.

To increase the sensitivity in detecting differences in dust levels between the various possible parameter combinations, the water sprays at the top and bottom of the cutting head facing the cutter were turned off during the test cycles. However, the water sprays at the gathering head and conveyor were in operation. Thus, the effects of secondary dust generation was minimized.

Additionally, during each test cycle, information was recorded about the drum speed, sump and shear velocities, the three-phase instantaneous watts, and voltage. Also, the three-phase head motor watts were integrated into watt-hours over the complete test cycle and listed separately for the left and right motors. A typical strip chart record for a given test is shown in figure 7. Other information recorded included noise level during testing, coal size distribution for 300- to 500-pound samples, and a secondary measurement of airborne dust using a light-scattering dust monitor.

The test program was developed in several stages. In the first stage, preliminary debugging and determination of the machine capabilities, crew training, and instrumentation were accomplished (1). The second stage was a fully operative experimental program. In the first stage, two sets of parameters were compared while working a similar butt face in the working section of the mine. The initial tests contrasted dust generation at 51 rev/min and a 1.5-inch depth of cut to that at 9 rev/min at 2.0-inch depth of cut. In both cases, the bit angle was held at 45° with an 8-inch bit spacing. Data were recorded in terms of milligrams of dust generated per ton of coal won.

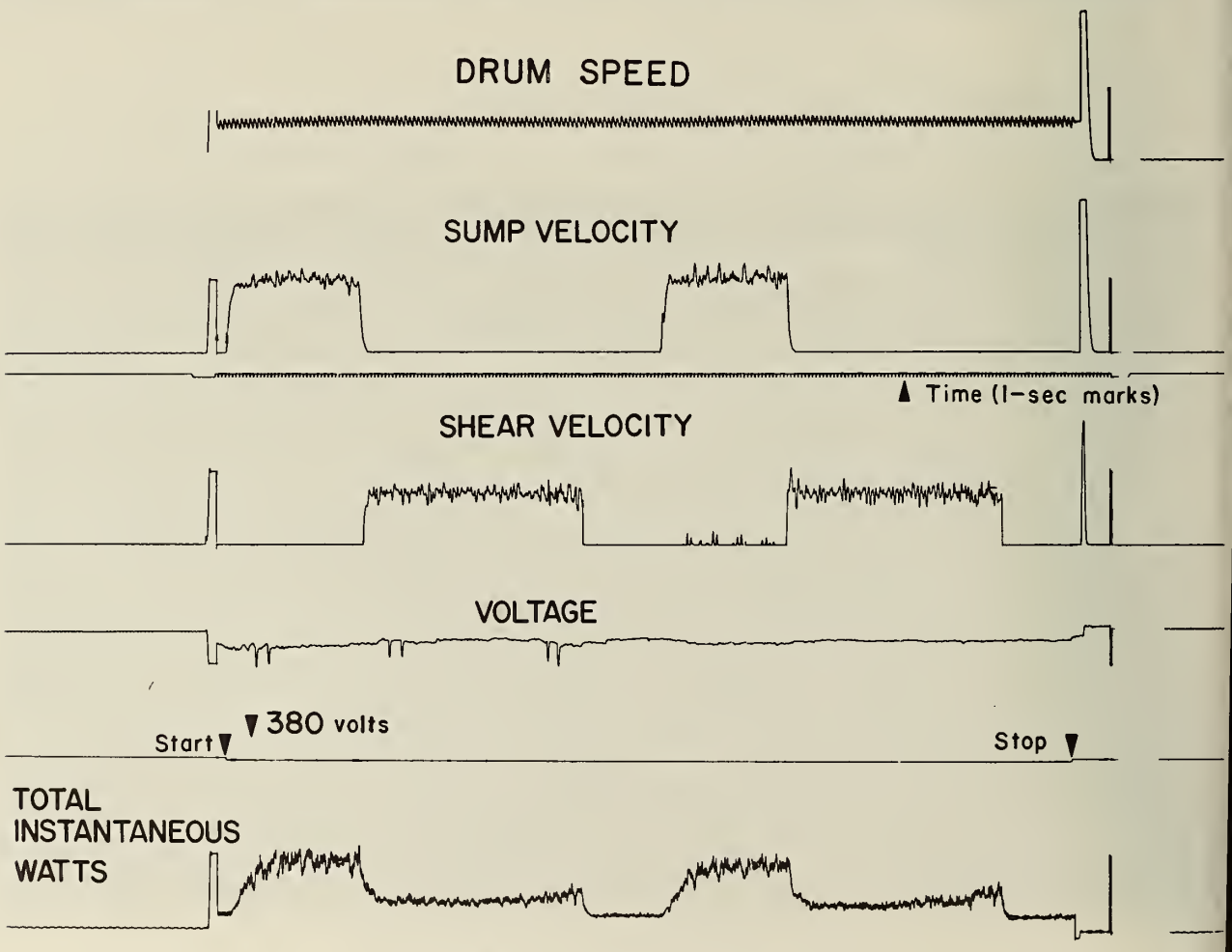

FIGURE 7. - Sample strip chart.

The results are summarized in table 2 and represent three replications with a statistical significance of 98 percent.

TABLE 2. - Stage 1 results--Respirable dust reduction using deep-cutting miner, milligrams per ton

Conditions	Station 1	Stations 3 and 4
51 rev/min, 1.5-inch cut depth, 45° bit angle, 8-inch bit spacing	5,809	5,315
9 rev/min, 3-inch cut depth, 45° bit angle, 8-inch bit spacing	1,122	3,230
Difference, percent	-80	-39

Although the results are presented in terms of milligrams per ton, it is expected that any mine operator using deep cutting and yet maintaining present-section airflow and production will achieve similar percentage reduction in milligrams per cubic meter.

Considering the heterogeneous nature of coal, the fact that a major difference was readily detected within only three replications reflected favorably on the significance of that difference. It also indicated the adherence of the test crew to a rigorous test procedure. It is a fact that as experimental technique and measurement accuracy deteriorate, the number of test replications must be greatly increased to maintain the confidence level of the result.

As a result of the preliminary tests, the stage 2 experiments concentrated only on the machine parameters of revolutions per minute and depth of cut per revolution. These are outlined in table 3.

TABLE 3. - Stage 2 test program--Mechanical cutting parameter for deep-cutting miner

	Group 1	Group 2	Group 3
Drum speed, rev/min	9	18	51
Depth of cut per revolution, inches	1	2	3-1/2
Bit spacing, inches	4	4	4
Bit angle, degrees	45	45	45

Although the results of these tests are still under study, certain data and conclusions are apparent. Figure 8 graphically shows the respirable dust in milligrams per ton recorded at stations 3 and 4 for the various depths of cut. The same curve is applicable at all three drum speeds. It is clear that there is a decrease in airborne dust levels resulting from increased depth of cut. Moreover, it is significant that the dust level does not appear to be dependent on bit speed.

These results are significant because it had been previously believed, based on British and the Bureau of Mines tests, that bit speed was a major source of entrainment of airborne dust created during the fragmentation

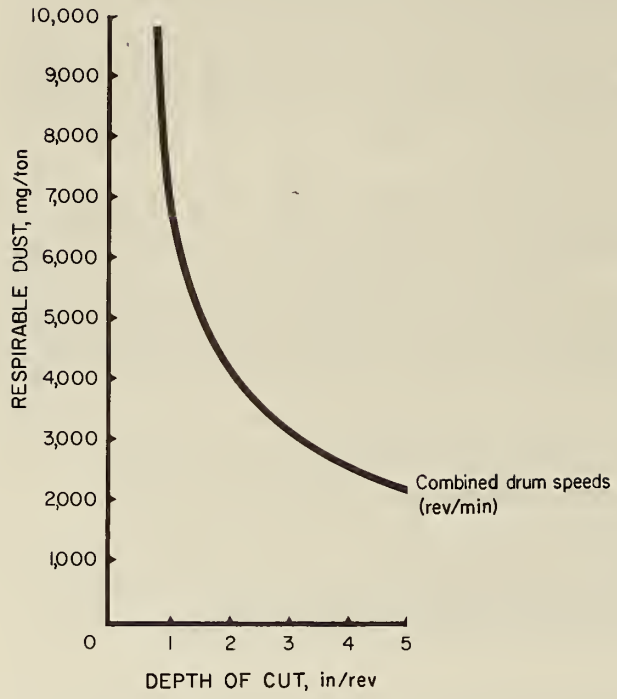

FIGURE 8. - Respirable dust generation versus depth of cut at stations 3 and 4 (in air return).

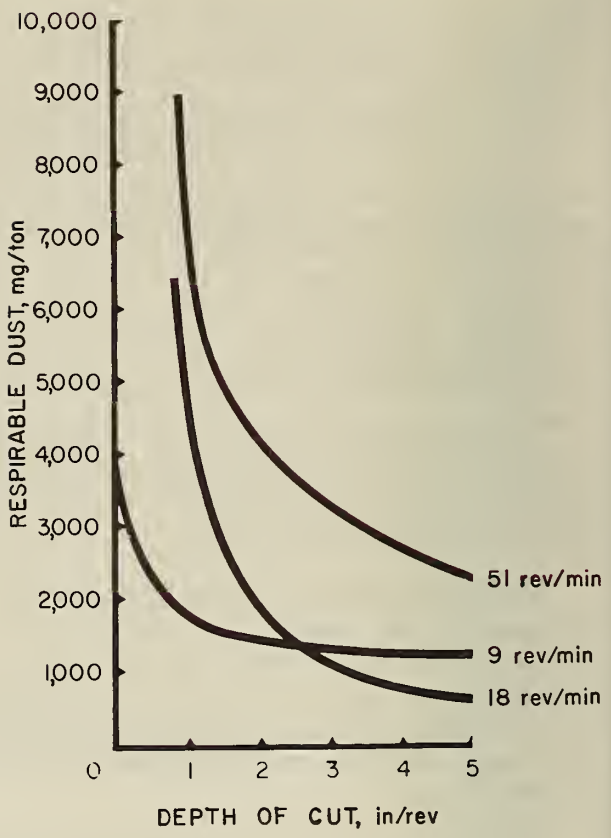

FIGURE 9. - Respirable dust generation versus depth of cut at station 1 (at machine operator).

process. However, the results of the IRRI sampling at stations 3 and 4 (relatively far from the fragmentation point) refute the earlier contention.

Figure 9 shows the relationship of dust, depth of cut, and drum speed at the operator's location (station 1). Here, it is apparent that the respirable dust level is both a function of depth of cut and station speed. It is hypothesized that the drum fanning action is responsible for the recirculation of the dust back to the operator's position, but such fanning action would not affect the dust measurement at stations 3 and 4 behind the brattice.

The dependency of depth of cut and drum speed at the mining machine is also corroborated by the data gathered at station 2 and depicted in figure 10. In the future, experimenters will have to pay strict attention to the position of the dust-sampling instruments and the amount of air circulation to achieve proper interpretation of test data.

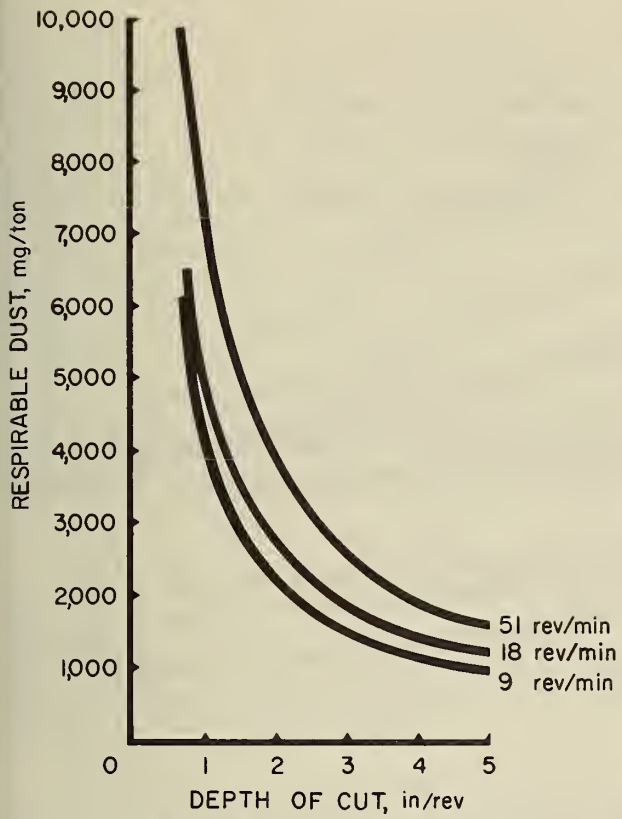

FIGURE 10. - Respirable dust generation versus depth of cut at station 2 (in front of operator).

The preliminary and full-scale tests have also produced some interesting results relative to specific energy as a function of depth of cut and bit spacing. Figure 11 shows that specific energy for both sump and shear decreases with depth of cut. (Note that the specific energy for shear is 50 percent of the comparative sump values.) Additionally, it is apparent that a 4-inch bit spacing is optimal in terms of specific energy throughout the 1- to 4-inch depth-of-cut range. Moreover, no significant effect appears attributable to the effect of drum speed.

Several benefits can directly or indirectly be traced to the carefully controlled experiments conducted in the first two stages of the program. In addition to strongly reinforcing many of the British and Bureau of Mines justifications from past laboratory research efforts, this IRRI-Bureau of Mines program has gained a greater degree of confidence and understanding in the overall nature of the coal-cutting process, which should assist other test programs in their field tests and demonstrations. In the long run, it should also lead to the ultimate reduction in research costs associated with developing new coal mining machinery. Indeed, taking advantage of this program's findings, already several equipment manufacturers are offering some new models with deep-cutting capability. Unfortunately, retrofitting is not easy, but it is possible with machines that have the necessary head horsepower and gear train design.

The HH 456 is currently ready for production tests. Figure 12 shows the relationship of the sump cutting rate for different drum speeds and depth of cut. The upper sump limit of a 5-inch depth of cut is based on the available spacing from the tip of the bit to the base of the drum. The upper limit further assumes the presence of a thrusting rig to provide the necessary normal force for such depth of cut. However, this experimental thrusting rig is not practical for production usage; therefore, operation would be limited to approximately a 3-inch depth of cut by the maximum traction anticipated from the crawler tracks. On the other hand, the shear jacks on the HH 456 can be used in regular production operation up to a 5-inch depth of cut. Thus, it will be possible, using sump and shear graphs similar to those shown in figure 12, to select a particular set of operating conditions and determine the probable production rate.

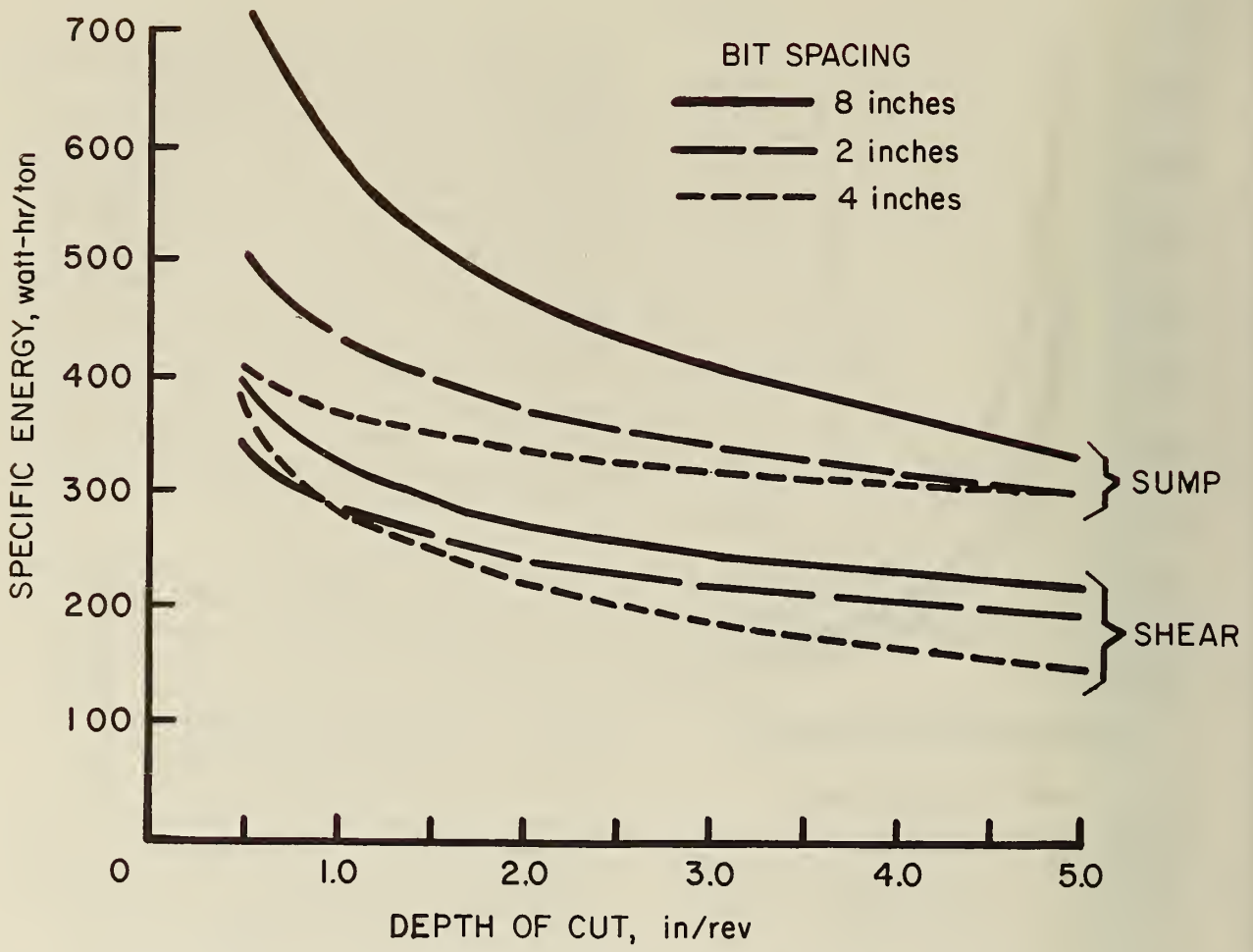

FIGURE 11. - Power curve fits of specific energy versus depth of cut butt coal.

Table 4 lists a set of suggested operating production parameters at which reduced dust generation could be evaluated.

TABLE 4. - Recommended parameters for HH 456 production test

Bit speed, rev/min	Depth of cut, inches		Average production, tons/min
	Sump	Shear	
51.....	0.8	1.5	5
18.....	2.4	4.3	5

It is also suggested that for the production tests, the water sprays to the cutter head be turned on for safety. It is further recommended that the test section be operated as would any normal working part of the mine, complete with two shuttle cars, one dual-arm roof bolter, etc. This also assumes that the mining company will strictly adhere to a repeatable mining plan and maintain proper levels of ventilation. Under these conditions, it should be possible to compare the quantities of airborne dust in the return air for both sets of parameters discussed in table 4. Assuming that average production

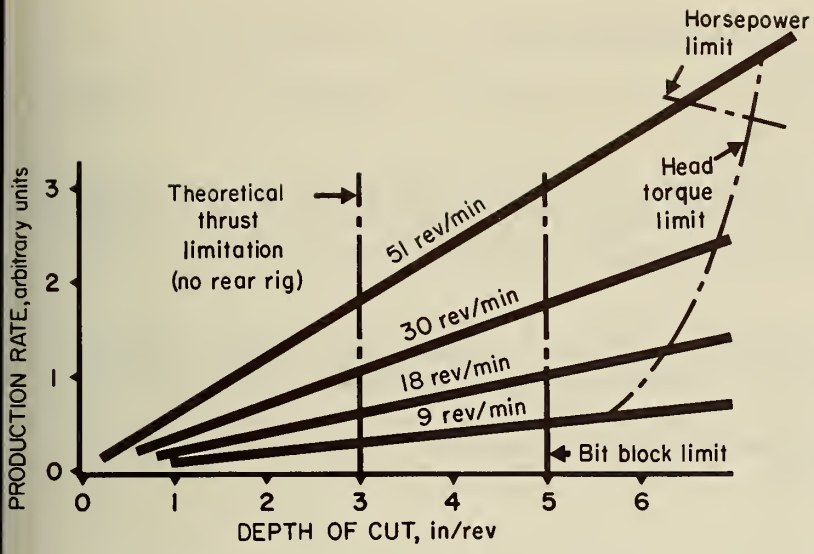

FIGURE 12. - Sump cutting rate versus depth of cut.

under both sets of conditions is the same, it is expected that the respirable dust in milligrams per cubic meter will be considerably lower for the deeper cuts than for the shallower cuts.

The new energy emphasis on higher production means that more tons of coal must be produced by each mine shift. Under the present mining situation, this would result in more total generation of dust per shift, unless innovative improvements such as deep cutting can be adopted. Although the principle promises lower respirable dust, it alone may not solve the problem. Improvements in ventilation and water spray techniques are also necessary in the overall program to reduce airborne dust levels.

The deep-cutting principle is an extremely valuable contribution. On the one hand, for the miners, it can be viewed as an initial advance into reducing the risk of black lung disease and minimizing possible dust explosions. Also, deep cutting presents the possibility of achieving practical production rates at lower bit speeds, which will reduce the possibilities of face ignitions. On the other hand, the winning of coal through deep cutting promises a larger product size for the consumer and reduced energy consumption per ton of coal produced for the miner operations.

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GUIDELINES FOR SELECTING DUST COLLECTORS FOR USE IN COAL MINES

by

Edward F. Divers[1]

ABSTRACT

Mechanical dust collectors (scrubbers) have a strong potential for controlling dust in underground coal mining operations. The Bureau of Mines has developed and assisted in the development of several types of small, high-dust-collection-efficiency scrubbers suitable for coal mine face, section, and belt transfer applications. Extensive laboratory and underground tests have determined the efficiency and provided practical guidelines for the application of each scrubber type.

For high-efficiency dust collection, the Bureau-developed venturi and the commercial flooded-fibrous-bed type are superior to any scrubber tested to date, achieving dust collection efficiencies greater than 98 percent for respirable coal dust in laboratory tests. Wetted-fan scrubbers and the small-diameter-cyclone scrubbers can be best in terms of minimum size or power and water consumption.

Dust collection efficiency, air volumetric range, size, power and water consumption, approximate cost, and application of each type are described.

INTRODUCTION

Both the Federal Government and private industry took a stronger interest in scrubbers for coal mine dust control, especially for face operations, shortly after the introduction of the continuous miner in the United States in 1948. Various types of scrubbers were designed by industry and evaluated in coal mines. With few exceptions, only a small number of these scrubber designs are in use today because of a combination of large size, misapplication, mechanical problems, and relatively low dust collection efficiency.

However, field tests with these scrubbers did generally point out at least three distinct advantages: a strong potential for about 90 percent reduction in respirable face dust concentrations, improved face visibility, and less rock dusting required in return airways. Scrubbers also appear to be an especially powerful dust control technique for sections using blowing ventilation where personnel are exposed to dust-laden air returning from face operations.

The overall efficiency of the scrubber system in field application is the product of the laboratory scrubber efficiency multiplied by its efficiency in capturing the dust cloud. Relatively high capture efficiencies (above 80

[1]Mechanical engineer, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

percent) can be readily achieved in room-and-pillar development where the dust cloud is largely contained by the face coal and machinery. Longwalls and retreat mining usually present more difficult problems in dust cloud capture.

Bureau field tests have indicated that 8-hour average values of respirable dust concentrations of about 20 mg/m^3 can be encountered at the scrubber inlet with ripper-type continuous-mining machines; boring and auger machines and longwall shearers often encounter much higher dust levels. A dust collector efficiency of 90 percent would reduce a 20 mg/m^3 value to 2 mg/m^3 in the effluent from the scrubber. However, a higher efficiency scrubber, ranging up to a maximum of about 98 percent, would provide a safety factor and also would be required to reduce the higher dust concentrations encountered with borers, augers, and shearers. An efficiency above 98 percent for respirable dust is usually prohibitive in terms of power and water use. A scrubber that has 98-percent efficiency would result in one-fifth less dust in the scrubber effluent than would the scrubber that has 90-percent efficiency; that is, 2 percent versus 10 percent of the dust penetrates the scrubber and is present in the effluent airstream.

This paper summarizes laboratory and underground results of the Bureau's research and development program to develop inproved dust scrubbers. The program concentrated on small, simple scrubbers with high dust collection efficiency.

GARRETT STUDY

In 1969, the Bureau funded the Garrett Research Co. to evaluate prospective commercial scrubbers to determine their potential for reducing coal mine face dust concentrations to legal levels. Emphasis was given to scrubbers that were expected to have high collection efficiency for respirable-size coal dust.

Thirty-five commercial collectors were surveyed and eight were evaluated in detail in the laboratory. Results indicated that none were able to satisfy the size and efficiency constraints of underground coal mines. However, the report did state that the venturi scrubber looked best, but no satisfactory venturi scrubber was commercially available.

LABORATORY TEST FACILITY

In 1971, a laboratory test facility was constructed at the Pittsburgh Mining and Safety Research Center, Bruceton, Pa., to evaluate prospective scrubbers, determine their maximum potential, and to help develop new scrubbers.

Full-size scrubbers up to 10,000 ft^3/min can be tested in this laboratory facility (fig. 1). A wide range of respirable dust concentrations and size distributions typical of coal mine face operations can be set up and maintained for extensive periods of time. The laboratory test facility saves considerable time and effort by reducing the difficult and much more costly underground evaluation of scrubbers.

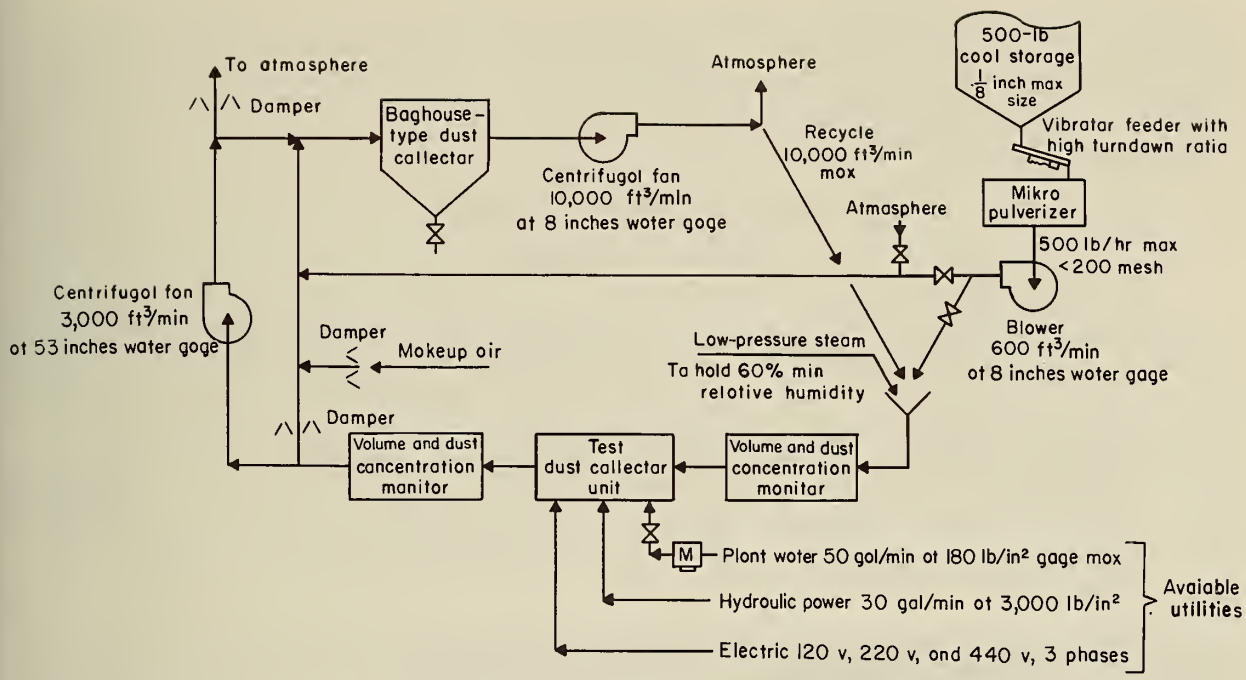
To atmosphere
Damper
Baghouse-type dust collector
Centrifugal fan 10,000 ft³/min at 8 inches water gage
Atmosphere
Recycle 10,000 ft³/min max
500-lb cool storage
1/8 inch max size
Vibrator feeder with high turndown ratio
Mikro pulverizer
500 lb/hr max <200 mesh
Atmosphere
Blower 600 ft³/min at 8 inches water gage
Centrifugal fan 3,000 ft³/min at 53 inches water gage
Damper
Makeup air
Low-pressure steam
To hold 60% min relative humidity
Damper
Volume and dust concentration monitor
Test dust collector unit
Volume and dust concentration monitor
M
Plant water 50 gal/min at 180 lb/in² gage max
Hydraulic power 30 gal/min at 3,000 lb/in²
Electric 120 v, 220 v, and 440 v, 3 phases
Available utilities

FIGURE 1. - Flow chart of dust collector test assembly.

RESULTS

Initial Test Program

From October 1972 through June 1973, five commercially available scrubbers were evaluated. These scrubbers either were not available during the Garrett contract or had been excluded from that study because they were not high-efficiency units.

Four of these scrubbers, all wetted-fan types, were already being used in underground coal mining operations; the fifth scrubber was the impaction-plate type.

Although the dust collection efficiencies of the wetted-fan type scrubbers were generally high, peaking near 90 percent on respirable-size coal dust, none appeared to have a strong potential for reducing anticipated respirable dust concentrations below the 2-mg/m^3 level. Size and mechanical problems also troubled some of the units.

New or Improved Scrubbers

More recent Bureau tests indicate that several additional types of scrubbers merit special attention for underground use due to their small size, low cost, simplicity, and safety. The types described below are representative of the better scrubbers for coal mine use in the power and water ranges specified. The dust collection efficiencies listed for each scrubber type

are based on extensive Bureau laboratory tests on respirable-size coal dust at typical face concentrations. A cascade impactor was used to determine the fractional efficiency in these laboratory tests. In all cases, higher efficiencies were achieved with increased water flow rate and increased pressure drop across the scrubber.

High-Efficiency Scrubbers

Venturi Scrubber

In July of 1973, a Bureau program was initiated to determine if any scrubber suitable for coal mine use could achieve the desired efficiency of greater than 90 percent. The venturi scrubber, consisting of a restriction in a duct with a water spray upstream of the restriction, was selected for initial work. Since a suitable venturi scrubber was not commercially available, a venturi was designed and fabricated by the Bureau (fig. 2). Laboratory tests soon showed that the venturi scrubber had a very high dust collection efficiency for respirable-size coal dust with reasonable fan power and water rates.

FIGURE 2. - Lab tests on 3,000-ft^3/min prototype Venturi scrubber.

Air pressure differentials across the venturi restriction (throat) should range from about 7 to 20 inches of water gage for coal mine use, and spray water rate should be about 3 to 7 gal/min per 1,000 ft^3/min air volume. Within these air pressure and water rate limits, respirable coal dust collection efficiencies range from about 80 to 98 percent. Cost is roughly $2 per ft^3/min. The venturi scrubber is relatively free from clogging problems and can be used where very coarse particulate is encountered or where high dust collection efficiency is required. Owing to the relatively high water use and fine mist created, the venturi normally requires a water-droplet eliminator. The Bureau has recently tested a new commercial vane-type eliminator that removes over 90 percent of the slurry water at eliminator face velocities of 2,000 ft/min and low air-pressure drop. Initial field tests of this eliminator look especially promising.

Along with a high dust collection efficiency, the venturi scrubber also possesses most of the other characteristics desirable for a good underground scrubber:

1. Small size, simple, rugged construction, low maintenance, low initial costs.

2. Flexibility. Its dust collection efficiency is limited only by fan pressure and water use. The throat section is easily adjustable to compensate for various air volumes and dust-pressure losses.

3. Essentially nonclogging. The collected dust can be continuously drained. Slurry or slurry water can readily be reused by the venturi.

4. Operation is not affected by machine orientation or tilt, such as those scrubbers using a sump.

5. Does not split the airstream (no purge or bleed air).

6. Safe. There are no inherent permissibility problems.

A venturi scrubber suitable for coal mine use is still not commercially available but can be readily designed and easily fabricated by most sheet metal shops. Venturi scrubbers for approximately 3,000 and 6,000 ft^3/min were designed and fabricated by the Dust Control and Life Support Group at the Pittsburgh Mining and Safety Research Center. Design drawings are available.

The venturi scrubber does require more water than other types of scrubbers; however, very low pressure water can be used by the venturi if the throat differential pressure is above 12 or 13 inches water gage. Also, pressure drops above 6 inches water gage are required to achieve reasonable dust collection efficiencies, and this requirement somewhat limits the selection of fans.

Wetted Fibrous-Bed Scrubber

Recent laboratory tests have indicated that a new type of scrubber not only can match the dust collection efficiency of the venturi but can accomplish it with a lower air pressure drop across the scrubber.

Early in 1975, the Bureau tested a stainless steel, loosely woven wire material developed by E. I. duPont de Nemours & Co. for scrubber application in the chemical industry. Dusty air is drawn through a dense bed of the wire material at a velocity above 30 ft/sec. Water sprays are placed immediately upstream of the wire bed to completely wet the bed surface. Water flow rates typically range from about 1 to 5 gal/min per 1,000 ft^3/min, although recent tests indicate that a fairly high dust-collection efficiency can also be achieved with less than 1 gal/min per 1,000 ft^3/min. The pressure drop across the bed should range from about 3 to 15 inches water gage for coal mine application. At a face velocity of 2,000 ft/min, a bed thickness of roughly one-fourth inch will result in a 2-inch water-gage-pressure drop, and a bed thickness of roughly 1 inch will result in a 15-inch water-gage-pressure drop. Efficiencies for respirable coal dust range between 90 and 98 percent and are higher than all previously tested scrubbers for comparable conditions. This high efficiency was maintained with air pressures as low as 2.5 inches water gage across the material.

Following these tests, and based on a Bureau design, DuPont fabricated two 2,000-ft^3/min scrubbers suitable for face operations. The scrubber consists of a commercial 2,000-ft^3/min two-stage vane-axial fan, a short duct transition at the fan inlet, and a 1-foot by 1-foot by 1/4-inch-thick bed of commercial, loosely knit, wire material. Spray nozzles are installed in the duct immediately upstream of the media to insure complete wetting. Slurry drain slots and pipe connections are installed on both sides of the wire material. The scrubber is 13 inches high, 12-1/2 inches wide, and 42-1/2 inches long, including the fan, which is MESA approved for coal mine use. The scrubber (fig. 3) also includes a suitable 2,000-ft^3/min eliminator to remove water drops from the scrubber airstream.

One distinct advantage results from the 2,000-ft/min face velocity of the wire material which is the same as that through the droplet eliminator; transitions from the wire material to the droplet eliminator or air ducts can be simple 1-to-1 ratios.

Although this type of scrubber has the highest collection efficiency measured to date with any scrubber approximating its small size, it may be more susceptible to clogging and is somewhat expensive, costing between $2 and $3 per ft^3/min.

Medium-High-Efficiency Scrubbers

During development of the venturi scrubber the Bureau modeled main, secondary, and auxiliary ventilation systems. It was found that relatively low volumes of air through the scrubber (1,500 to 3,000 ft^3/min) could be surprisingly effective in controlling dust at the face. This was somewhat

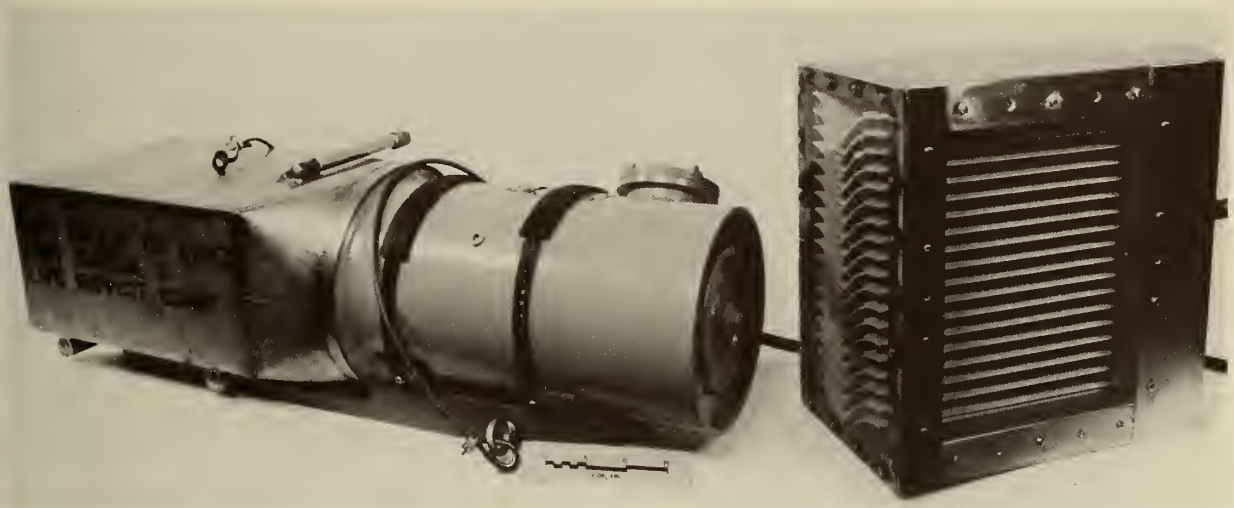

FIGURE 3. - One model of a 2,000-ft^3/min wetted fibrous-bed scrubber. A suitable 2,000-ft^3/min Euroform eliminator (top removed) on right.

contrary to European practice, where high volume and, therefore, relatively large scrubbers are emphasized.

Based on commercially available hardware and applications that would be suitable for both low coal and machine-mounted applications, the Bureau directed its program toward the development of a family of small, inexpensive and rugged scrubbers. All of the scrubbers utilized a commercially available, MESA-approved, 2,000 ft^3/min vane-axial fan powered by an internal 6-horsepower electric motor developing 6 inches water gage. The height of these scrubbers including fan was held to less than 15 inches, width less than 16 inches, and length less than 50 inches. Along with the DuPont flooded fibrous scrubber discussed previously, three additional types of scrubbers having a medium-high dust collection efficiency were investigated or developed: a wetted fan, wetted brush, and the small-diameter cyclone types. These scrubbers merit special attention for underground use due to their simplicity and low cost. They also can be adapted to large air volume systems with appropriate design changes.

Note that the venturi scrubber is not included; it requires pressures above 6 inches water gage.

Wetted-Fan Scrubber

The wetted-fan scrubber consists of a heavy-duty fan, centrifugal or axial type, with a water spray at the fan inlet (fig. 4). Fan differential pressures normally range from 1 to 5 inches water gage. Water flow through the spray nozzles generally ranges from 1 to 3 gal/min per 1,000 ft^3/min of scrubber air-volume capacity. The centrifugal wetted fans have a higher dust collection efficiency than the vane axial wetted fans. Dust collection

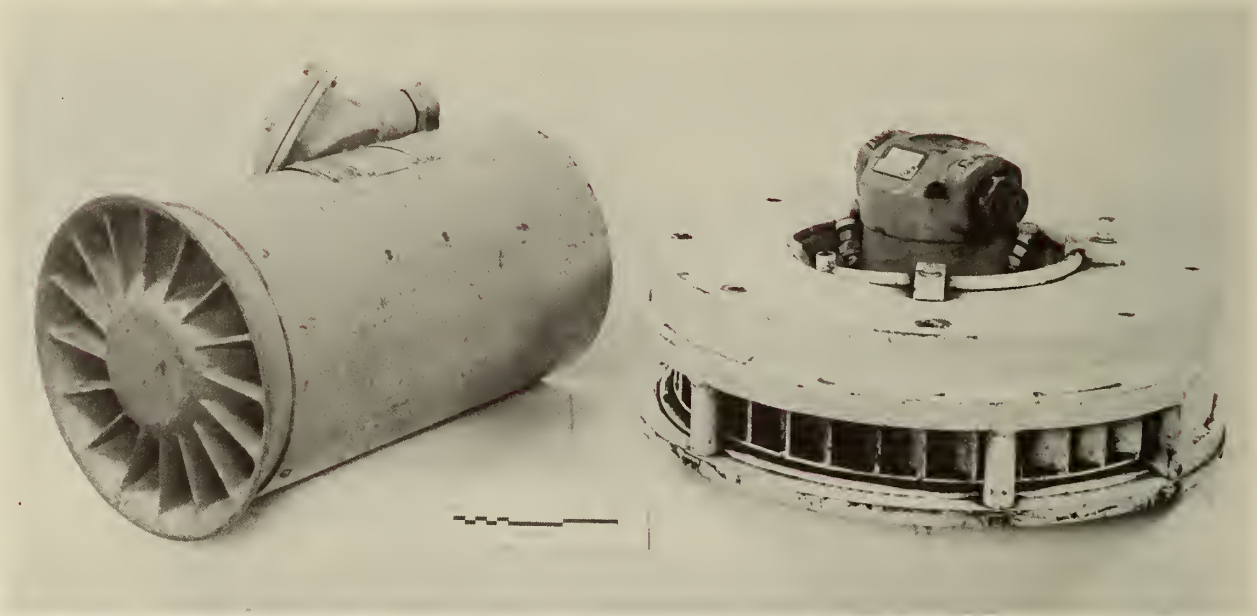

FIGURE 4. - Wetted-fan scrubbers. The 2,000-ft^3/min internal electrically driven Joy 5112 Vane-axial fan on the left can be readily converted to a wetted-fan scrubber by adding water sprays, less than 4 gal/min, to the fan inlet. The 2,000-ft^3/min hydraulic driven Gundlach centrifugal fan on the right was designed as a wetted-fan scrubber.

efficiency ranges from about 70 to 90 percent. The wetted fan scrubber is the smallest and least expensive of the four. Cost, including an approved coal mine fan, can be under $1 per ft^3/min.

Wetted-Brush Scrubber

The dust collection efficiency of the wetted-fan scrubber can be greatly improved, that is, to better than 90 percent, without a significant increase in size or cost by adding a bed of stainless steel or plastic wire brushes upstream of the fan and placing the water sprays upstream of the brushes (fig. 5).

The brushes can be identical to those commonly used to wash bottles, with 2- or 3-inch outside diameter and several inches long with radial wires extending from a central rod. The brushes can also be purchased commercially.

Cyclone Scrubbers

The small-diameter cyclone-type scrubber (fig. 6) consists of a panel of side-by-side cylindrical cyclone tubes. Tube diameter is usually less than 4 inches. Each tube has an air volume capacity roughly from 40 to 250 ft^3/min, depending on the tube diameter and air pressure differential across the tube. Pressure drops normally range from 2 to 5 inches water gage. Water flow rates from the scrubber spray nozzles usually range from 1/2 to 3 gal/min per 1,000 ft^3/min of scrubber capacity. Dust collection efficiency ranges from

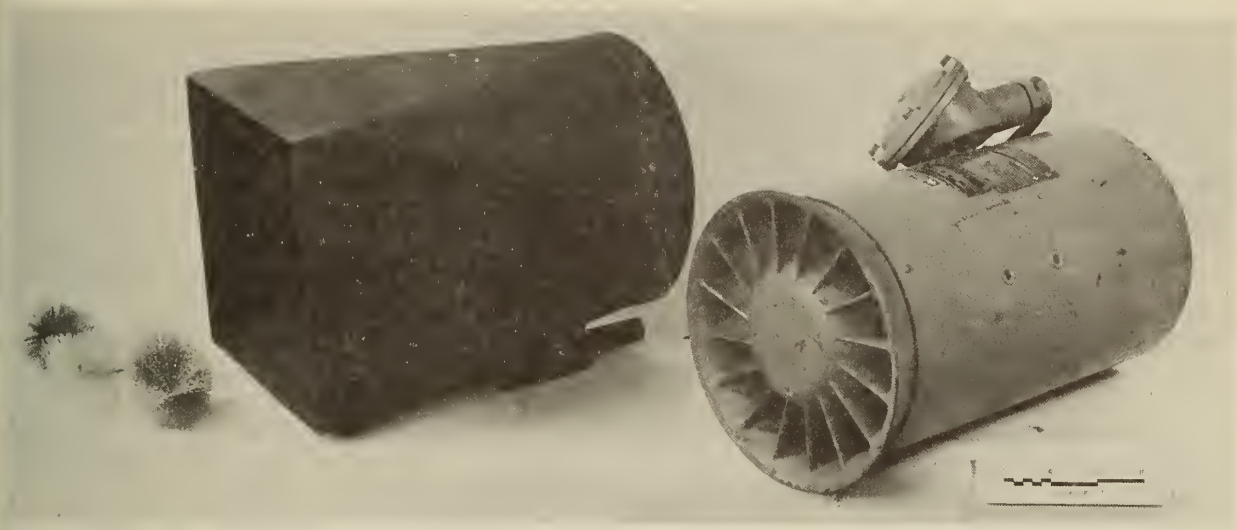

FIGURE 5. - Wetted-brush scrubber. Typical brushes, transition with drain and 2,000-ft^3/min fan. A wire mesh retainer in the transition holds approximately 28 stainless steel brushes in this scrubber.

FIGURE 6. - Small-diameter cyclone-type scrubbers, showing Merix panel (left) and Donaldson panel (right). Transition for the Donaldson and an appropriate 2,000-ft^3/min Joy fan are also shown.

about 80 to 93 percent. Cost is roughly $2.50 per ft^3/min of scrubber volumetric capacity.

The cyclone-type scrubber is recommended where minimum use of water is desirable and medium-high efficiencies are acceptable. The slurry water is usually readily collected from cyclone-type scrubbers without the use of a separate water-droplet eliminator.

Low-Water Scrubber

A different scrubber recently tested by the Bureau was the APAR Air Washer (ECAR Products, Inc.). This 1,200-ft^3/min, 5-horsepower, wetted-fan scrubber required only 6 gallons of water per hour, or about one-tenth the water flow of other scrubbers. However, its collection efficiency for respirable dust was relatively high, over 85 percent. The size of this scrubber probably excludes it from face applications, but the low water consumption appears to offer distinct advantages for other mining operations such as belt-transfer applications. Cost is roughly $4 per ft^3/min.

DISCUSSION

Except for the venturi, the scrubbers previously described do not include mist or droplet eliminators to reduce the water content of the affluent air. Addition of the eliminator adds significantly to the size and cost of a scrubber. The Bureau is now testing several commercial eliminators (Merix, Eurofoam) to evaluate their performance at high face velocities, above 1,800 ft/min, to keep the eliminator size to a minimum. Laboratory and field tests of the Eurofoam eliminator look especially promising.

Another approach to the water problem is to develop scrubbers with very low water consumption. Tests at low water rates of the A-PAR, DuPont, and small-diameter-cyclone scrubbers are encouraging.

SUMMARY

Several of the small, rugged, high dust-collection-efficiency scrubbers that have been developed and tested appear to have attractive features for dust control applications in coal mining operations. The Bureau of Mines research work indicates that at least two types of scrubbers, the venturi and the wetted fibrous bed, have adequate dust collection efficiencies for coal mine applications. Primary effort is now being directed toward the application of these scrubbers on various mining machines and the development of small, medium-high-pressure fans for use with the scrubber and associated face ventilation systems.

Table 1 summarizes the recommended scrubber for mine applications and special requirements.

TABLE 1. - Recommended scrubbers

	Scrubber types
Application:	
Machine mounting, [1] 2,000-4,000 ft^3/min.....	Flooded fiber. Small-diameter cyclone. Wetted fan.
Section, 4,000-6,000 ft^3/min.....	Flooded fiber. Venturi. Small-diameter cyclone.
Belt transfer, 1,000-2,000 ft^3/min.....	APAR. Flooded fiber. Small-diameter cyclone.
Special requirements:	
High efficiency (operate above 6 inches water gage).	Flooded fiber. Venturi.
Low water consumption (less than 1 gal/min per 1,000 ft^3/min).	APAR. Small-diameter cyclone. Flooded fiber.
Very coarse or sticky particulate.....	Venturi.
Smallest possible size.....	Wetted fan. Wire brush.

[1] For blowing ventilation, use larger air volume.

CONTROL OF RESPIRABLE DUST BY VENTILATION

by

Natesa I. Jayaraman[1]

ABSTRACT

The use of ventilation as a dust control technique is reviewed in this Bureau of Mines paper. An attempt to develop extensible brattice techniques in order to alleviate the inconvenience associated with maintenance of face ventilation was largely unsuccessful; however, an improved extensible duct system for a Goodman borer was developed.

A particularly powerful dust-control technique is secondary exhaust ventilation, in which the dusty air is vacuumed up and either ducted to the return or passed through a machine-mounted dust collector and the cleansed air is discharged at the mining machine. Field studies have been conducted of secondary ventilation dust control systems for Wilcox Mark 20 and Jeffrey 100L augers, for Eickhoff EDW 340L and Sagem 300 DTS longwall shearers, and for a Jeffrey Heliminer. Field results for the Mark 20 auger indicated reductions of the respirable dust at the jacksetter position of 90 percent. Approximately 50-percent reductions were obtained for the 100L auger, the Eickhoff and Sagem shearers, and the Heliminer. Design and construction of secondary ventilation systems for a Goodman borer and Joy 11 drum-type continuous miner are presently in progress.

INTRODUCTION

Ventilation, which is the principal technique for controlling respirable dust generated at the face in the entry, can be divided into three general types: Conventional face ventilation, secondary blowing ventilation, and secondary exhaust ventilation.

Conventional face ventilation--Brattice or ducting is used to direct the intake airstream toward the face or the exhaust airstream away from the face.

Secondary blowing ventilation--Machine-mounted diffuser fans are used to "push" the face dust away from nearby personnel and into the return.

Secondary exhaust ventilation--The newly formed face dust is vacuumed from the vicinity of the face through air intakes by a machine-mounted fan and then either discharged into the return via a duct or passed through a machine-mounted dust collector. The cleansed air is discharged at the mining machine.

When carefully used, ventilation is a highly effective technique for controlling respirable dust. However, proper use of brattice or ducting to

[1]Mining engineer, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

achieve good face ventilation is burdensome to the mine personnel and can reduce productivity. Although secondary blowing ventilation is becoming increasingly popular for methane control at the face, techniques for dispersing methane will also disperse the dust, and detailed engineering guidelines are required. In principle, secondary exhaust ventilation is probably the most powerful dust control technique available to the mining industry, but engineering guidelines are again required regarding, for example, the location of the air intakes, the air quantities required for effective dust control, and particularly the interaction between the secondary and face airflow systems.

It should be noted that secondary exhaust ventilation using a machine-mounted dust collector is the only ventilation technique that reduces the amount of airborne respirable dust in the total ventilation airstream, and thus reduces the dust exposure of downstream personnel.

This paper reviews the Bureau's research and development activities to improve face and secondary exhaust ventilation systems. Studies to investigate improved secondary blowing ventilation systems are in progress but are not reviewed here. The Bureau has found laboratory-scale models to be very useful to obtain engineering guidance regarding ventilation parameters at minimal cost.

CONVENTIONAL FACE VENTILATION

Face ventilation can be divided into exhaust and blowing ventilation. With exhaust ventilation, the major amount of the incoming ventilation air passes directly into the return within about 5 feet beyond the end of the brattice or ducting, and the actual airflow nearer the face is small. Therefore, little use is made of the main ventilation air for dust removal if the brattice is too far from the face. Figure 1 shows a laboratory-scale model of a Wilcox Mark 20 auger mining machine. The left panel shows a simulated 20-foot brattice, and the right panel shows a 10-foot brattice. Smoke is used to represent the newly formed face dust. The reduction in dust dispersion by moving the brattice from 20 to 10 feet from the face is evident. In practice, an 80-percent reduction in dust is achieved at the right jacksetter location. For comparison, doubling the face ventilation achieved only a 50-percent reduction at the right jacksetter with the 20-foot brattice. Thus, dust reduction is much more effective by moving the brattice closer to the face than by increasing the amount of face ventilation.

However, in actual practice, maintenance of the required 10-foot distance is burdensome and can significantly decrease productivity. The development of an extensible brattice-and-ducting system would increase productivity while maintaining a low-dust environment. Several types of extensible systems have been developed in the past, but they have not been widely accepted by the mining community because of inconvenience or interference with the mining cycle. A Bureau contractor recently reexamined the feasibility of extensible systems. A simple, extensible duct system was developed for a Goodman boring machine in which flat and rigid fiberglass ducting bridged the entry (fig. 2) and a sliding section telescoped into the

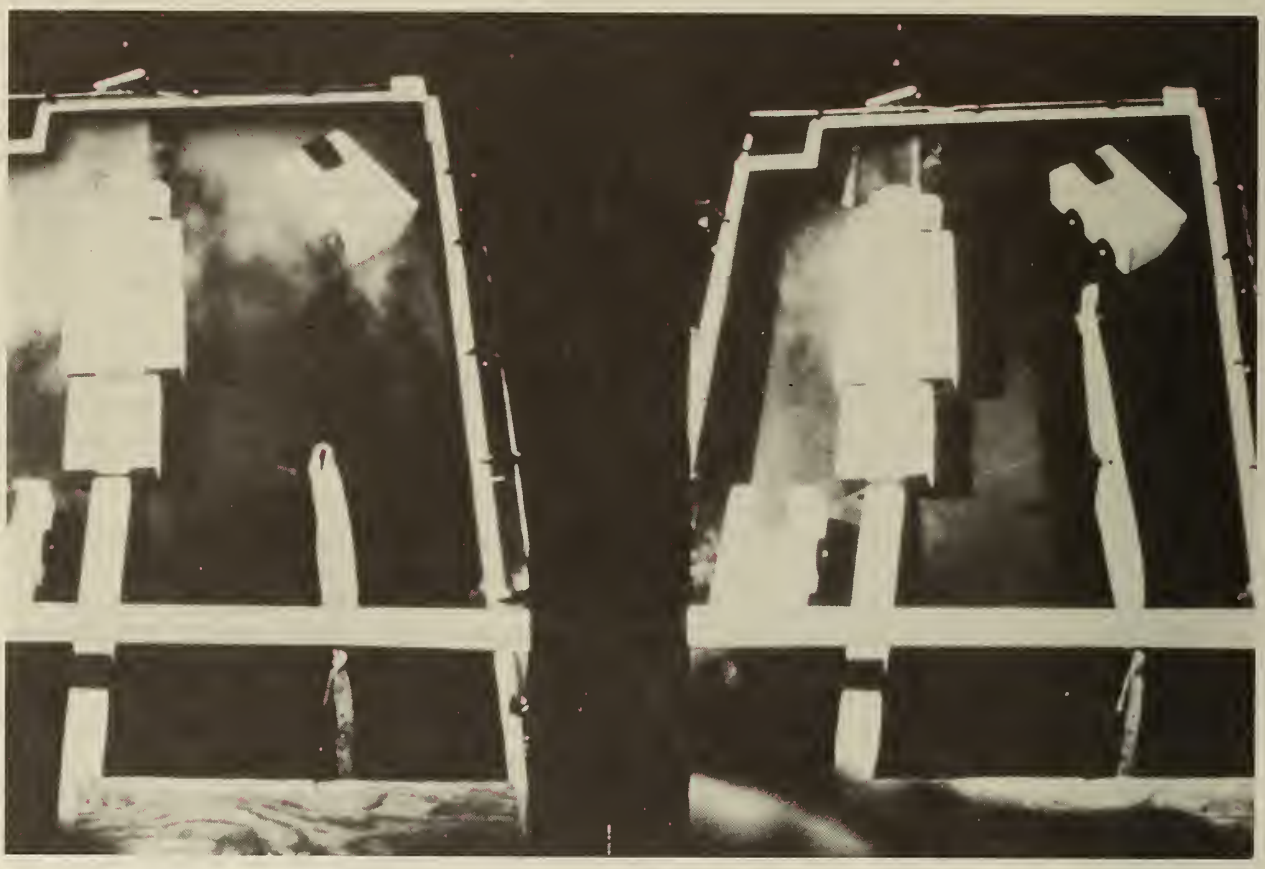

FIGURE 1. - Reduction in dust by moving brattice from 20 feet from face (left) to 10 feet from face (right).

face end of the roof-mounted duct (fig. 3). The telescoping section can easily be extended by hand, or the end can be attached to the machine for automatic extension. A dramatic reduction in dust levels in the vicinity of the face was visually apparent, although quantitative numbers are not yet available. More important, the extensible duct system was very well received by the section personnel.

Several extensible brattice systems were also developed by the contractor, but field tests indicated that they did not readily meld into the mining operations at the selected test sites. Improved designs are being prepared for consideration by mine operators.

FIGURE 2. - Extensible duct–bridge section.

The foregoing items involve physical extensions of the brattice or ducting. An alternative extensible system is a machine-mounted air curtain to "extend" or supplement the brattice or ducting system. Under a Bureau contract, Donaldson Co. is examining the feasibility of developing such a system. The system currently consists of a 12-foot-long section of slotted pipe running the length of the machine to the right of center (fig. 4). A machine-mounted fan drives about 800 ft^3/min of air through the slot upward toward the roof. Laboratory tests are promising, and field tests are being scheduled.

FIGURE 3. - Extensible duct–telescoping section.

Blowing face ventilation provides better airflow across the face area than does exhaust ventilation and a greater distance can be tolerated between the face and the end of the brattice or ducting. Blowing ventilation thus can reduce the interference of the brattice or ducting with mining operations. However, the blowing ventilation air automatically tends to pass the new face dust back over the machine operator, shuttle car operator, and other nearby personnel. With exhaust ventilation, the ventilation air automatically tends to carry the face dust away from section personnel and into the return. For example, a field survey at a section using a Goodman boring machine indicated that the respirable dust exposure was reduced by about 75 percent for the machine operator, shuttle car operator, and roof bolter by using exhaust face ventilation instead of blowing face ventilation.

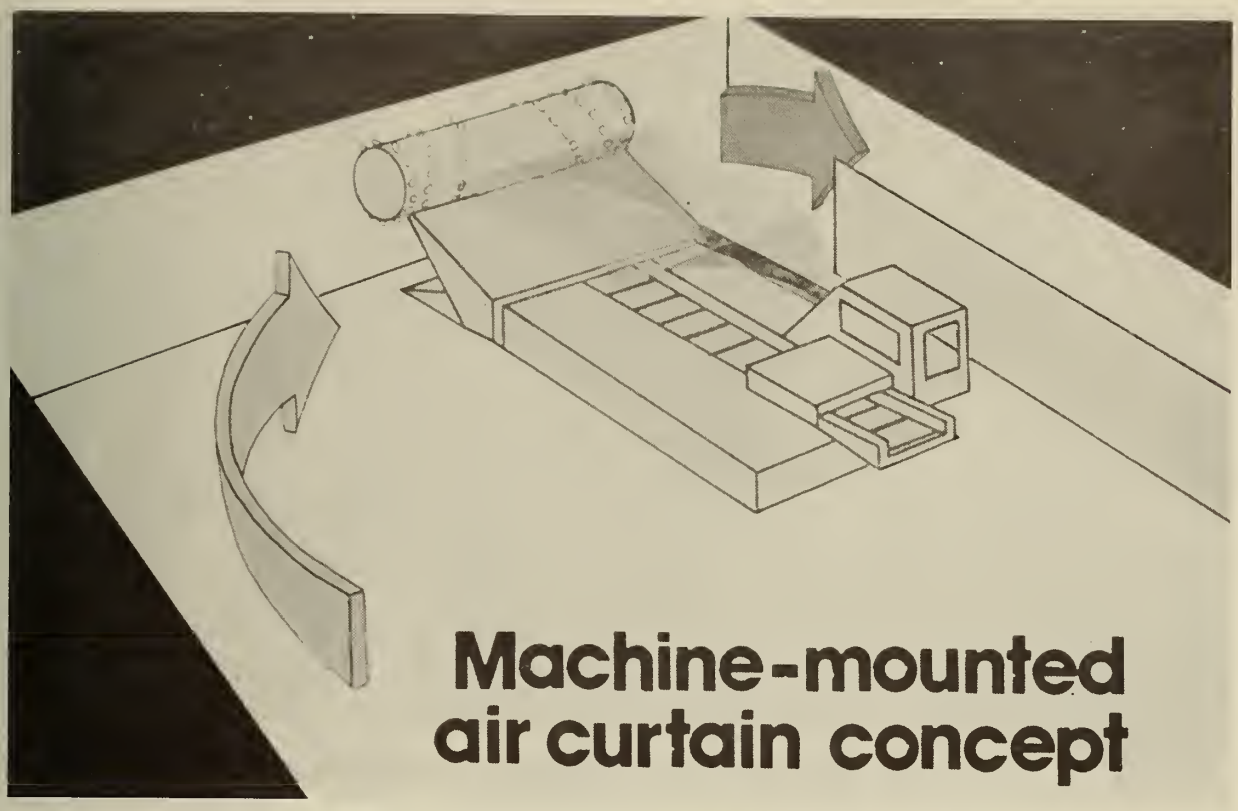

FIGURE 4. - Air-curtain concept for extensible brattice.

SECONDARY VENTILATION

Secondary ventilation, where the newly formed face dust is vacuumed from the vicinity of the face and either discharged into the return via a duct or passed through a machine-mounted dust collector with the effluent air discharged at the mining machine, is a very effective dust control technique. Figure 5 shows a one-fifth-scale laboratory model of a Joy 12 CM continuous miner modified to include secondary ventilation. Exhaust face ventilation is being used with brattice positioned 30 feet from the face. The left photograph shows the dispersion of the face dust when no secondary ventilation is used. The reduction in dust with secondary exhaust ventilation is shown on the right. However, space constraints on the mining machine often severely limit the configuration of the air ducting, the location of the air intakes, and the installation of a fan or dust collector on the machine, and secondary airflow must be matched to the airflow into the entry in order to avoid local recirculation problems. Also, secondary ventilation is somewhat expensive compared with other dust control techniques such as water sprays.

It will be noted that the total dust reduction efficiency of a secondary ventilation system involves (1) the dust capture efficiency of the air intake (multiplied by the dust collection efficiency of the dust collector, if used) and (2) the complex interaction between the secondary and face airflow systems.

FIGURE 5. - Reduction in dust by secondary exhaust ventilation.

Laboratory-scale modeling has proved to be valuable in providing engineering guidance here.

The Bureau has been involved with several programs to design, install, and field test secondary ventilation systems on a variety of auger, borer, ripper, and shearer mining machines. The programs are discussed in the sections that follow.

Wilcox Mark 20 Auger

A field contract was implemented by the Bureau to install a secondary ventilation system on a Wilcox Mark 20 auger machine. The secondary ventilation system involved the following. (1) Two Joy 5112 fans installed in parallel in the middle of the machine above the pan (the pan was lowered to provide space above the pan), (2) shrouding the conveyor, and (3) ducting from the shroud to pass the effluent from the fan into the return (fig. 6). Figure 7 shows the two fans mounted above the conveyor in the machine. The fans are capable of drawing approximately 4,000 ft^3/min. The mine entry was 3 feet high and 26 feet wide and used line brattice and exhaust ventilation (usually about 3,600 ft^3/min).

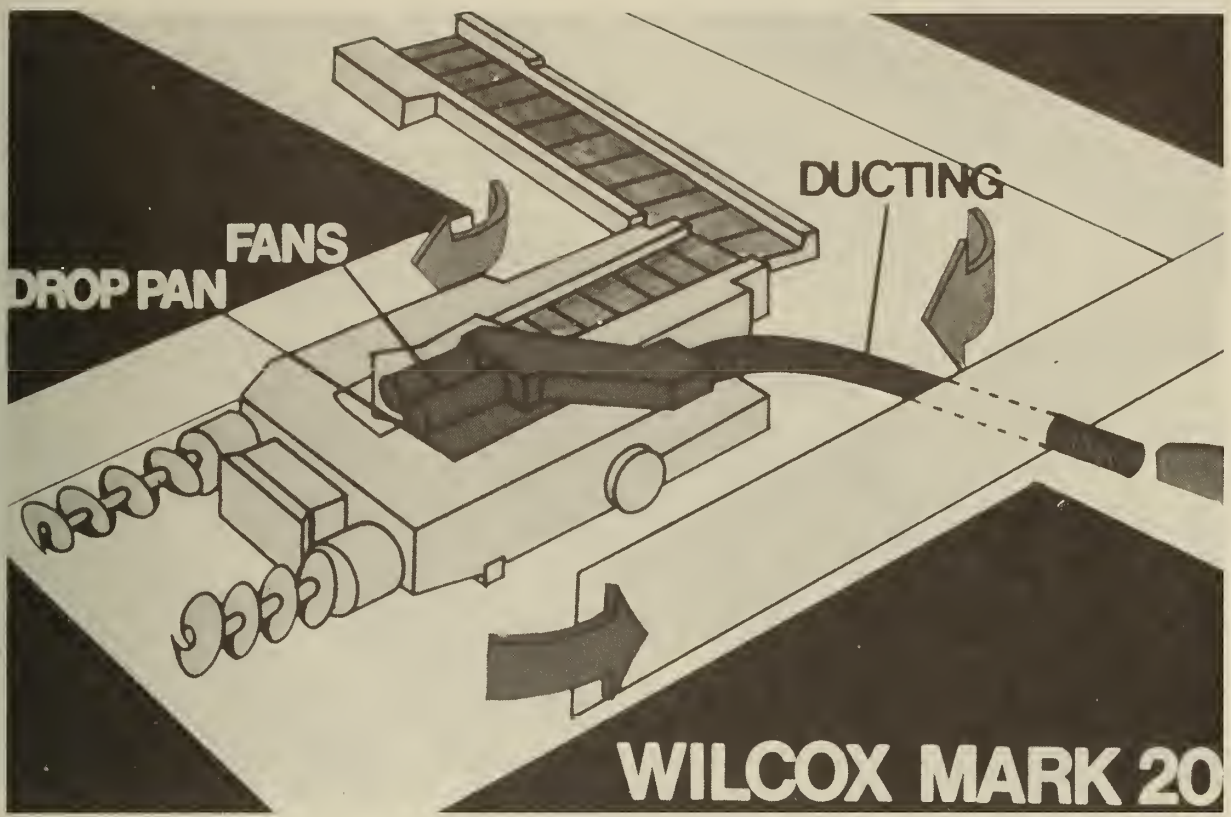

FIGURE 6. - Wilcox Mark 20 auger concept for secondary exhaust ventilation.

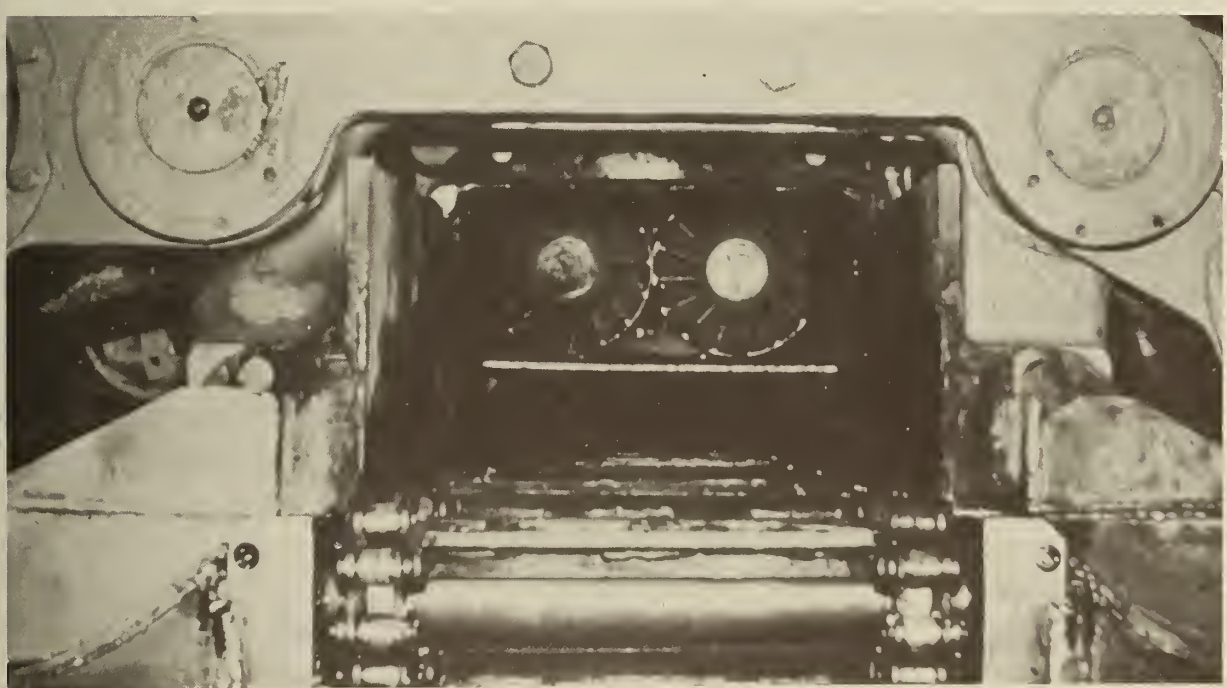

FIGURE 7. - Joy 5112 fans installed in Wilcox Mark 20 auger.

Laboratory-scale model tests[2] indicated that the amount of dust surrounding the jacksetter and machine operator could be reduced by about 90 percent with such a secondary ventilation system.

Results of the field tests are given in table 1. In the field, the intake air contained about 2.1 mg/m^3 of respirable dust. Taking this intake dust into account, there was a ~90-percent reduction in the face dust occurring at the jacksetter locations using a face airflow of 6,000 ft^3/min into the entry and a secondary airflow of about 4,000 ft^3/min.

TABLE 1. - Field respirable dust levels with Wilcox Mark 20 auger before and after adding secondary ventilation system, mg/m^3

	Before[1]	After[1]	Reduction, percent
Miner operator	0	0	-
Right roof bolter	1.3	1.4	-
Left roof bolter	4.9	2.3	53
Right jacksetter	9.1	1.0	89
Left jacksetter	15.2	1.4	91

[1] Intake dust level of 2.1 mg/m^3 has been subtracted.

While the dust reductions achieved with the secondary ventilation system were large, they were insufficient to achieve the 2-mg/m^3 standard for personnel exposure in the field test section because of the high level of dust in the intake air. However, if the intake dust were reduced to the usual ~0.1-mg/m^3 level, the section would be nearly in compliance.

Cost of the secondary ventilation system for the Wilcox Mark 20 auger is about $15,000. Clinchfield subsequently modified two additional machines to incorporate secondary ventilation.

Jeffrey 100L Auger

The Bureau recently initiated a contract with the Southern Appalachian Coal Co. to install a secondary ventilation system on a Jeffrey 100L auger. The concept (fig. 8) is basically similar to that of the Wilcox Mark 20 auger except that an air duct is mounted on the top of the 100L and two Joy 5112 fans are mounted on the right side of the conveyor. Flexible tubing connects the duct to the fans. Tubing also is used to pass the effluent from the fans to the brattice. Cost is approximately $10,000.

The influence of secondary ventilation or respirable dust levels with the 100L auger should be very similar to the results previously observed with the Mark 20 auger, and no lab modeling was done with the 100L.

Initial field tests indicated a 35-percent reduction in dust at the right jacksetter using 1,000-ft^3/min secondary ventilation directed to the return

[2] Stein, R. L., J. A. Breslin, and A. J. Strazisar. Investigation of Dust Control by Ventilation Using a Scale Model. Am. Ind. Hyg. J., v. 35, No. 12, 1974, pp. 815-824.

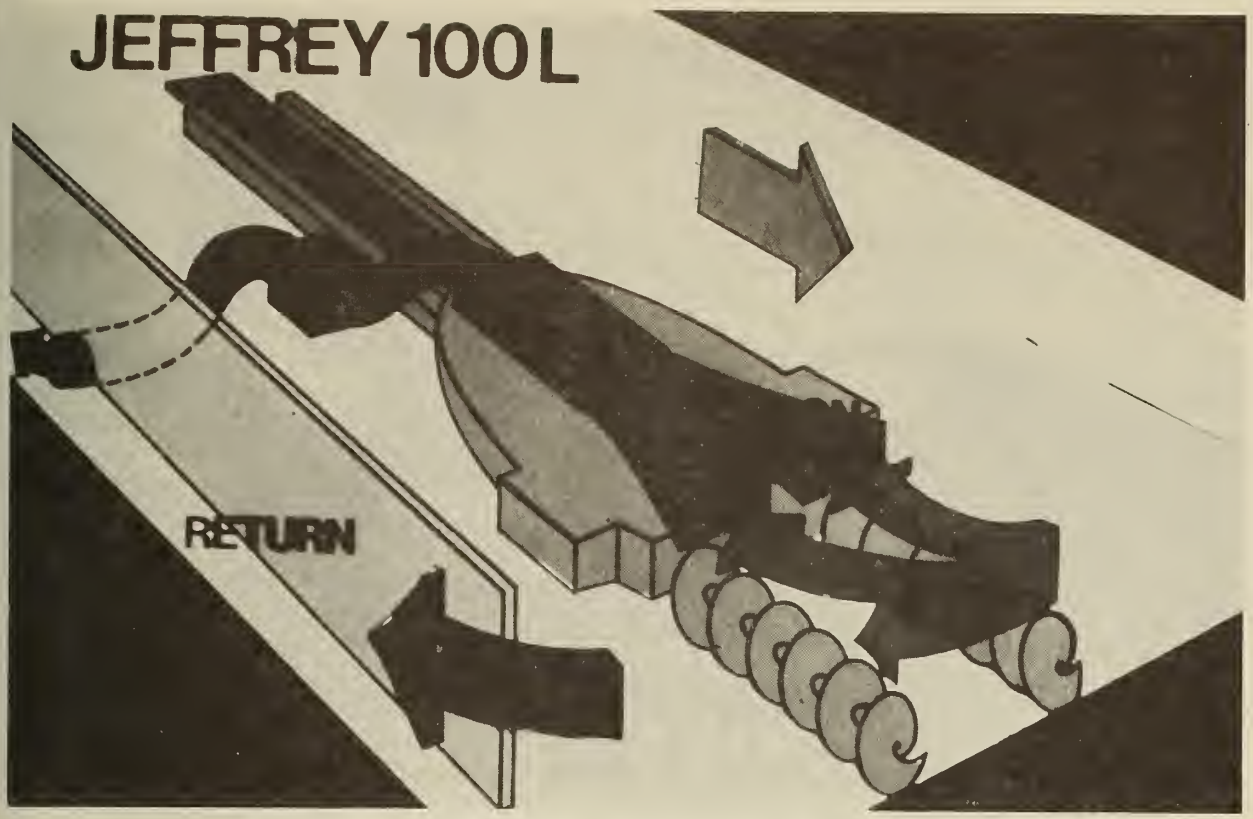

FIGURE 8. - Jeffrey 100L auger concept for secondary exhaust ventilation.

coupled with 5,000-ft^3/min face ventilation. Model results indicated that these secondary-to-face ratios are poor; that is, the secondary ventilation should be about one-third to one-half that of the face ventilation. A second Joy 5112 fan was installed in parallel with the first fan in order to increase the power of the secondary ventilation system. With about 1,600 ft^3/min of secondary air, reductions of about 50 percent were achieved in the face return at the entrance to exhaust line curtain.

Eickhoff 340L Longwall Shearer

Bureau field studies of dust sources associated with longwall mining using a shearer indicated that the major dust source along the face was the cutting action of the shearer drum. Dust associated with the face conveyor, chock movement, and gob fall appear to be less important.

The Bureau initiated a contract with Donaldson Co. to investigate the feasibility and effectiveness of a secondary ventilation system on the longwall shearer. An Eickhoff EDW 340L shearer was selected for modification. Examination of the physical design of the 340L indicated that there is a modest amount of physical space available underneath and at each end of the shearer to incorporate air ducting directly in the machine. Figure 9 shows the space available for air ducting and a dust collector and locations for air intakes.

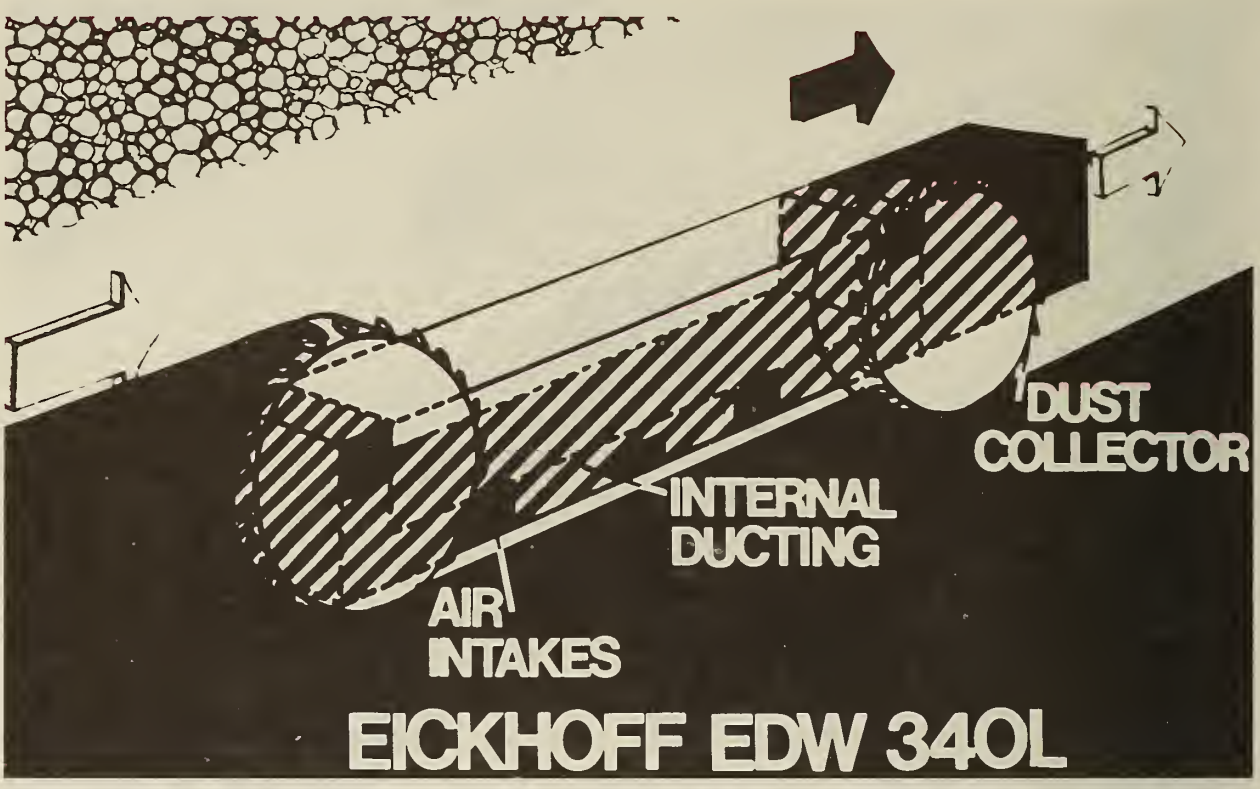

FIGURE 9. - Eickhoff 340L shearer concept for secondary exhaust ventilation.

FIGURE 10. - Dust collector installed on Eickhoff shearer.

Tests of laboratory-scale models indicated that the proposed air intake locations were satisfactory and that a 5,000-ft^3/min secondary system coupled with a very efficient dust collector should reduce the dust exposure of the shearer operator by about 80 percent with about 15,000-ft^3/min face ventilation.

Consultation with Eickhoff indicated that the 340L could be modified to include the simple air intake and air ducting system without affecting the physical integrity of the shearer.

The machine used in the field tests was modified accordingly; the bottom of the underframe was closed off with 1-1/2-inch steel plate, and the enclosed space was used as an air duct with air intakes attached at each end of the shearer. A 5,000-ft^3/min Donaldson dust collector was attached to the downstream side of the machine (fig. 10). Cost was approximately $30,000.

Field tests indicated a 50- to 60-percent reduction in respirable dust exposure halfway down the face. This reduction closely matches the predicted values based upon an 80-percent air intake efficiency multiplied by an 80-percent dust collection efficiency of the Donaldson collector. The dust reduction at the tailgate was only 40 percent; this lesser reduction was due to pneumatic picks being used there to break up large slabs of fallen roof and thereby acting as a secondary dust source.

Present plans are to install a 6,000-ft^3/min secondary system on the shearer in order to increase the dust reduction.

Sagem DTS 300

In association with Eastern Associated Coal Corp., the Bureau designed a secondary ventilation system for a Sagem 300 longwall shearer. Figure 11 schematically shows the modified machine. An air intake was located near the upstream drum. An air duct placed on top of the shearer arm led to two Joy 5112 fans, which acted as wetted-fan scrubbers. The effluent from the scrubber was directed downward between the machine and the coal face. Cost was approximately $8,000.

Up to 50-percent reduction in respirable dust was measured by an instantaneous dust monitor at the tailgate operator. This was less than predicted on the basis of laboratory data for modeling and scrubber efficiency and may have been due to reentrainment of dust by the high-velocity airstream exiting from the scrubber (2,000 ft/min). Also, the downstream jacksetters were exposed to this reentrained dust.

Goodman 405 Borer

Respirable dust is often a severe problem in coal mine sections in which borer-type mining machines are used because it is difficult to ventilate the face when the machine occupies most of the cross-sectional area of the entry. Also, many borer sections use blowing face ventilation, and, as noted earlier,

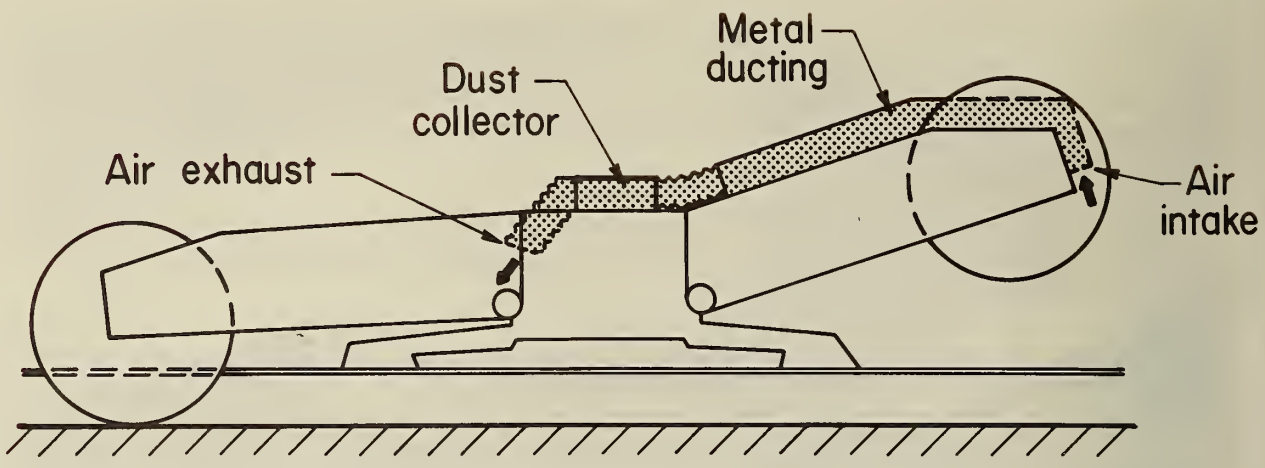

FIGURE 11. - Sagem DTS 300 shearer concept for secondary exhaust ventilation.

this method of face ventilation is not very effective in controlling respirable dust.

The Bureau initiated a contract with Old Ben Coal Co. to investigate the effectiveness of secondary ventilation with a Goodman 405 twin-boring machine. It is difficult to mount a dust collector and fan directly on the borer because of limited space, and this contract is oriented toward developing a transfer car behind the borer for the dust collector and fan. Figure 12 shows the concept.

Laboratory-scale modeling indicated that, with blowing face ventilation, the secondary air quantity should be sufficient to draw fresh air through the main body of the entry. For example, to achieve 90-percent dust reduction, 6,000-ft^3/min of secondary air must be used if 3,000 ft^3/min of blowing air is being used; that is, if the entry is ventilated with 3,000 ft^3/min of blowing air from the ventilation duct or brattice, an additional 3,000 ft^3/min must be drawn up the entry.

Since the contract includes a field investigation of the effectiveness of secondary ventilation with blowing face ventilation, a 6,000-ft^3/min secondary ventilation system was designed by the Bureau. A Bureau-designed 6,000-ft^3/min venturi collector was included.

The physical layout of the borer is such that the contractor had to design an air duct for the top of the borer, which involved a somewhat tortuous flow path. Since the tortuous flow path could involve excessive pressure losses that could not be handled by the fan, a wooden full-scale simulated duct was built to permit laboratory testing of pressure losses in the duct and also the performance of the venturi collector. Figure 13 shows the simulated secondary ventilation system. Significant pressure losses occurred but they were not excessive.

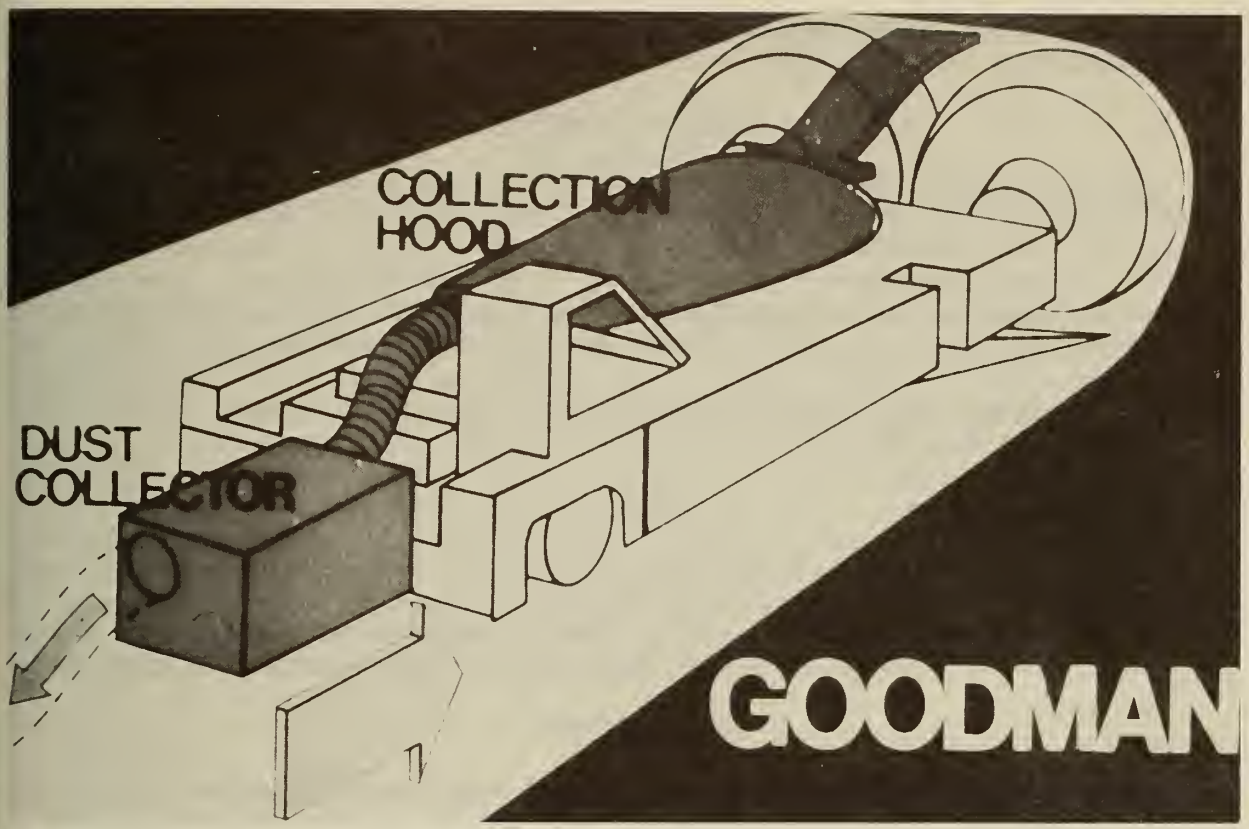

FIGURE 12. - Goodman 405 borer concept for secondary exhaust ventilation.

FIGURE 13. - Simulated air duct for Goodman borer.

Initial field tests indicate a ~65 percent reduction in respirable dust at the operator. Cost is difficult to estimate at this time.

Jeffrey Heliminer

Peabody Coal Co. recently conducted field tests with a Jeffrey Heliminer modified to include secondary ventilation. Air ducting is mounted on the top of the boom and connected by flexible ducting to a 5,000-ft^3/min DuPont dust collector mounted on the left rear fender of the mining machine. The effluent from the dust collector is discharged at the rear of the mining machine into the entry. The entry is operated with 5,000-ft^3/min blowing ventilation.

Field results by Peabody indicate about a 50-percent reduction in respirable dust with the secondary ventilation system.

Joy 12 CM

The Bureau recently initiated two programs to investigate the effectiveness of secondary ventilation with a Joy 12 CM, one with Peabody and the other with Westmoreland. Preliminary field tests by Peabody have indicated a ~90 percent reduction in respirable dust with the secondary ventilation system.

SUMMARY

The use of ventilation as a dust-control technique is reviewed. An attempt to develop an extensible brattice system to expedite maintenance of face ventilation was largely unsuccessful, although an improved extensible duct system for a Goodman borer was developed.

A powerful dust-control technique is secondary exhaust ventilation, where the dusty air is vacuumed up and either ducted to the return or passed through a machine-mounted dust collector and the cleansed air discharged at the mining machine. Results of field experiments with a Wilcox Mark 20 auger indicated reductions of the respirable dust at the jacksetter position of 90 percent with secondary ventilation. Approximately 50-percent reductions were obtained for a 100L auger, Eickhoff 340W and Sagem 300 DTS longwall shearers, and a Jeffrey Heliminer.

WATER INFUSION FOR DUST CONTROL

by

Joseph Cervik[1]

ABSTRACT

This Bureau of Mines paper reviews water infusion of coalbeds in both Europe and the United States as a method of dust control. Water infusion is widely practiced on advancing longwalls in Belgium, France, West Germany and, to some extent, Great Britain. In the three European infusion methods--face infusion, remote infusion, and infusion from the advance gate roads--drilling and infusion must be done concurrently with mining. Retreating longwalls used in the United States do not have these operational difficulties, however, and can be infused with, at most, two horizontal holes drilled from the rib sides of the panel. Although water infusion for dust suppression has not been successful in all U.S. coalbeds (such as those associated with tectonic activity), several successful tests have been conducted, with dust reductions ranging from 50 to 79 percent.

INTRODUCTION

Water infusion of coalbeds to suppress respirable dust during mining is a widespread practice in West Germany, France, Belgium, and, to some extent, Great Britain. Where infusion is possible, it is reputedly the best means of combating dust (7).[2] West German regulations require infusion of coalbeds where possible, and over 50 percent of the longwall faces are infused (8). That country's experience shows that a minimum of 1.6 gallons of water per ton of coal must be infused to suppress respirable dust (1). In Belgium, 2.4 gallons of water per ton of coal suppresses 95 percent of the dust, or 65 percent of the particles between 0.5 and 5 micrometers produced at the face (6). In the northern coalfields of France, water infusion is the basic dust-prevention technique and covers 89 percent of the coal produced (4). Compared with other European countries, water infusion is not common in Great Britian (5). The effectiveness of infusion in the Welsh coalfield is doubted and, in the Staffordshire coalfield, no significant improvements in dust conditions were noted during an infusion test. However, on retreating longwall systems in the Durham and Lancashire coalfields, dust reductions of 50 percent are reported on the Durham faces, and somewhat lower reductions, on the Lancashire faces.

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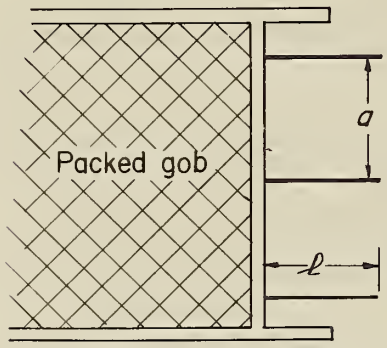
[1]Supervisory geophysicist, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

EUROPEAN DRILLING AND INFUSION PROCEDURES

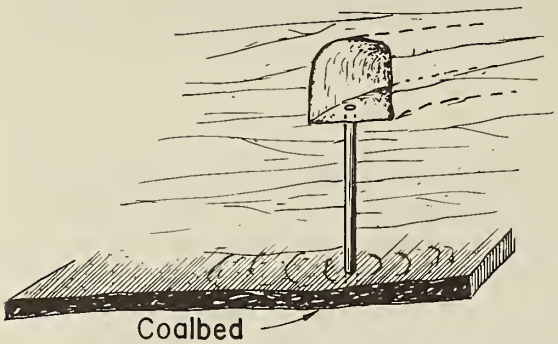
The predominate mining system in Great Britain and Europe is the advancing longwall. In Great Britain (5), for example, only 7 percent of the longwalls are worked on retreat. There are about 840 major longwall faces.



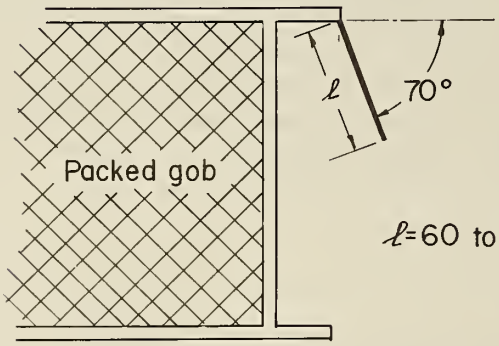
Shallow infusion
ℓ = daily advance rate
$a = 2\ell$

Deep infusion
ℓ = 40 ft
a = 80 ft

FACE INFUSION



REMOTE INFUSION



INFUSION FROM ADVANCE ROADS

FIGURE 1. - European infusion methods.

Integrating the drilling and infusion phases on an advancing longwall is more difficult than on a retreating longwall. Figure 1 shows three European methods of infusing advancing longwalls (1)--face infusion, remote infusion, and infusion from advance gate roads.

Face infusion, in which horizontal holes are drilled into the face, consists of two variations. In the first variation, shallow infusion, the holes are drilled to a depth of approximately the daily advance of the panel. The distance between holes is about twice the length of the holes. If the daily advance rate is 10 feet, then the hole length is 10 feet and the distance between holes is 20 feet. Further, if the panel is 400 feet wide, about 20 holes are necessary to infuse the panel. The second variation is deep infusion, in which holes are drilled to depths of about 40 feet. The spacing between holes is 80 feet, and about five holes are required on a 400-foot face.

The second method, remote infusion, is infusion from outside of the mined coalbed. If a roadway exists

above the panel being mined, holes are drilled downward from the roadway into the panel and infused continuously.

In the last method, infusion from advanced gate roads, holes are drilled at an angle of 70° relative to the axis of the roadway. The holes are drilled from about 60 to 120 feet deep. Infusion hose is grouted into the hole for distances of from 45 to 60 feet.

Each type of infusion has serious limitations. For shallow face infusion, a large number of holes must be drilled and infused daily, which causes production delays. This works well where manpower and equipment are available to complete the drilling and infusion phases in one shift. Although deep face requires a lesser number of holes, the infusion phase requires more time because a larger volume of coal is infused. In France, continuous shallow face infusion is practiced under certain special situations on plow faces (1). Infusion holes are drilled in the upper part of the coalbed and the infusion phase is conducted during mining. A plow mines the lower portion of the coalbed, and the top coal containing the holes falls. Continuous infusion can be carried out only on plow faces that advance slowly. In some cases, the infusion hoses are damaged when the top coal falls.

For remote infusion, drilling is more expensive because of harder or more abrasive rocks, and special drills are required. This method is not used widely.

Drilling holes in the advance gate roads does show promise providing certain operational problems can be solved. At present, advance headings on high-output faces in West Germany (1) are ahead of the face about 75 to 90 feet, even though these headings are manned 24 hours daily. Therefore, holes are drilled on weekends only. If problems develop during the drilling or sealing of the hole, infusion is not possible until the following weekend. In France (4), longwalls are infused from the advance gate roads and complemented by infusion into the face of the longwall.

U.S. PRACTICE

In the United States, all operating longwalls are the retreating type. There are no operational difficulties or production delays from incorporating drilling and infusion cycles during mining. Holes are drilled and infused from the rib sides of the panel (fig. 2), and these operations are independent of face operations. Even in room-and-pillar mining, integrating drilling and infusion phases into a mining cycle presents no serious problems or delays in mining. However, water infusion is used as a last resort in U.S. mining operations and is rarely applied. Bureau studies have shown that, in addition to suppressing respirable dust, water infusion in some cases substantially reduces the flow of methane through faces of a developmental section. In these cases, reduced dust levels mean a healthier working environment; and reduced methane flow means a safer working environment, potentially faster advance rates and, therefore, an improvement in production.

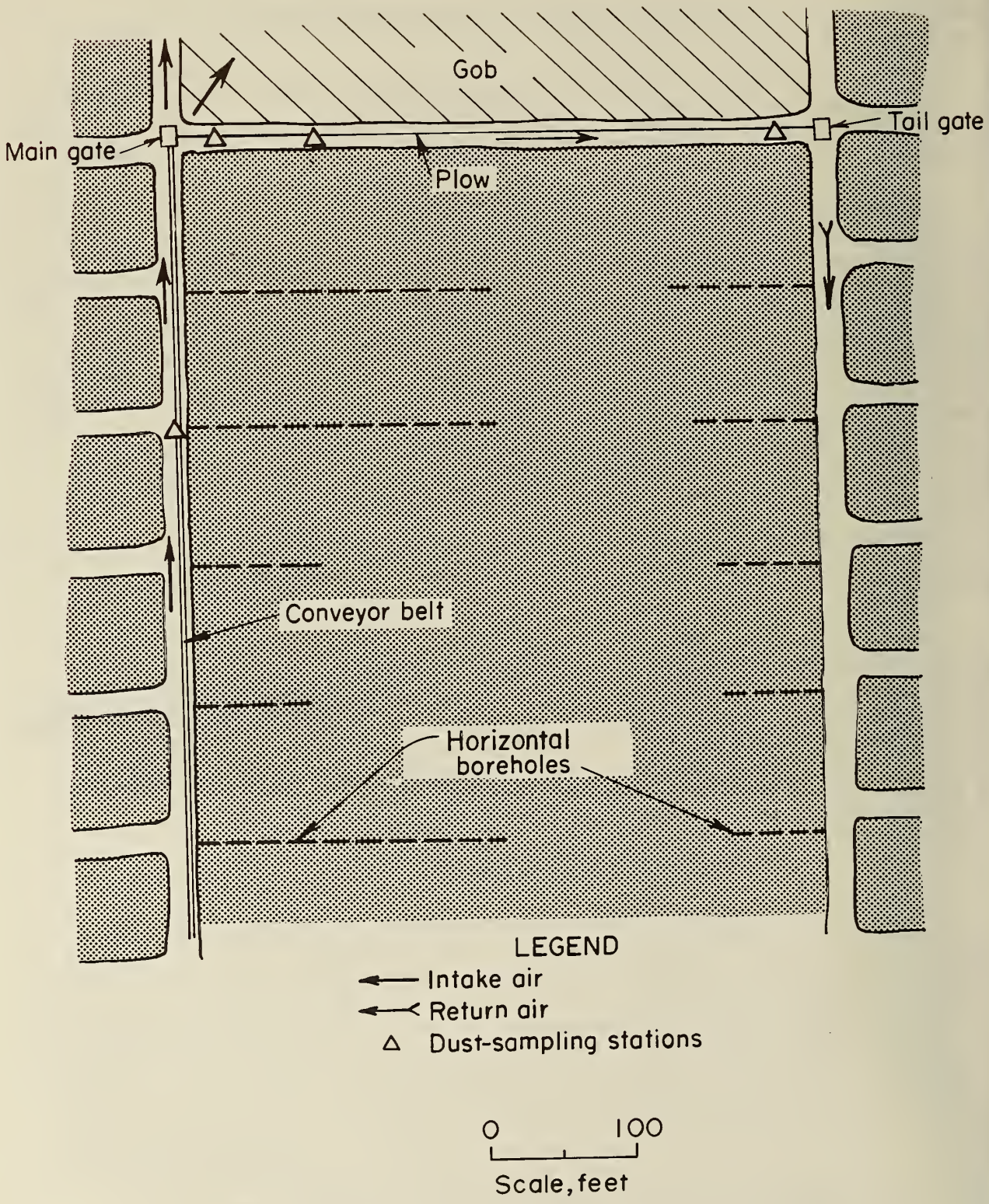


FIGURE 2. - Infusion hole location on retreating longwall.

INFUSION PROCEDURES

The migration of water through a coalbed during infusion cannot be observed, but problems can be diagnosed and solved providing the mechanics of infusion are understood and the infusion process can be visualized. Definite relationships exist among parameters such as hole length, spacing between holes, quantity of infused water, and panel or section width.

Infusion of a Developmental Section

When water is pumped down a wellbore and forced under pressure into a coalbed (fig. 3), its flow rate will be governed by the water pressure in the wellbore and the fracture permeability of the coalbed. Figure 4 shows a visualization of the migration of water from the wellbore into the coalbed. Fracture permeability of the coalbed has been assumed to be constant and even in all directions, therefore, water moves away from the wellbore accordingly. The circles show the successive positions of the flooded zone with time. If water is pumped into the coalbed through two wells (fig. 5) separated by a small distance, the two flooded zones around each wellbore will merge eventually and continue expanding as one oval front.

The preceding discussion is applicable also to horizontal holes drilled from underground locations into the coalbed. However, water should enter the coalbed from a small segment at the back part of the hole. This condition can be met by filling the hole with inflatable packers (fig. 6). Good results are obtained when 5-foot packers are connected with joints of 5-foot pipe (2). If too few packers are used, water at the back part of the hole tends to short circuit along the hole instead of penetrating the coalbed. An alternative is to grout a 3/4- or 1-inch plastic pipe into the hole (3). For example, if infusion holes are drilled to a depth of about 125 feet, plastic pipe is grouted into the hole for a distance of about 110-115 feet. This leaves 10 to 15 feet of open hole at the inby end for infusion into the coalbed.

When a coalbed is infused from an underground location, water spreads uniformly from the back part of the hole (fig. 7) and eventually reaches the mine entry (fig. 8). Water appears on the face areas as droplets and, when the face is covered with these water droplets, infusion is terminated. The total quantity of infused water ranges from 5,000 to 6,000 gallons. For a hole drilled to a depth of 125 feet and grouted as in the example described previously, the flooded zone is about 220 feet in diameter. Water has migrated about 110 feet beyond the end of the hole as well as 110 feet left and right of the hole.

A typical developmental section is about 500 feet wide. More than one is needed to completely flood the section. The second hole should be drilled less than 220 feet, and preferably about 170 feet, from the first hole. The flooded zone from the second hole will extend about 110 feet toward the first hole. If the spacing between holes is 220 feet, the two flooded zones just touch, which means unflooded or partially flooded zones exist between holes. Reducing the spacing to 170 feet or less insures that the flooded zones from adjacent holes not only touch but merge. A 500-foot-wide section requires

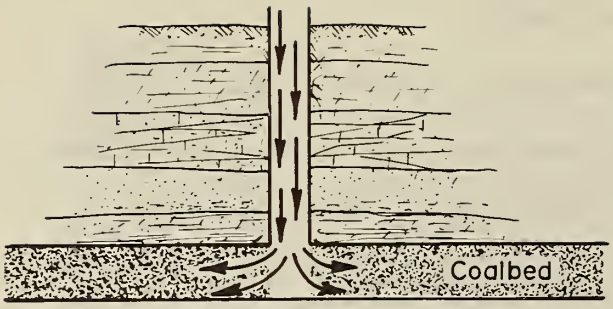


FIGURE 3. - Flow into coalbed through vertical borehole.

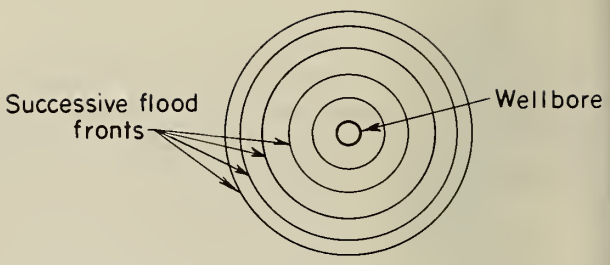


FIGURE 4. - Migration of water through coalbed.

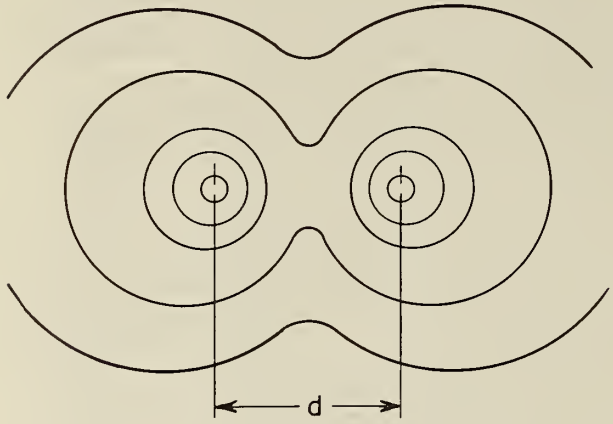


FIGURE 5. - Waterflood zones of two wells.

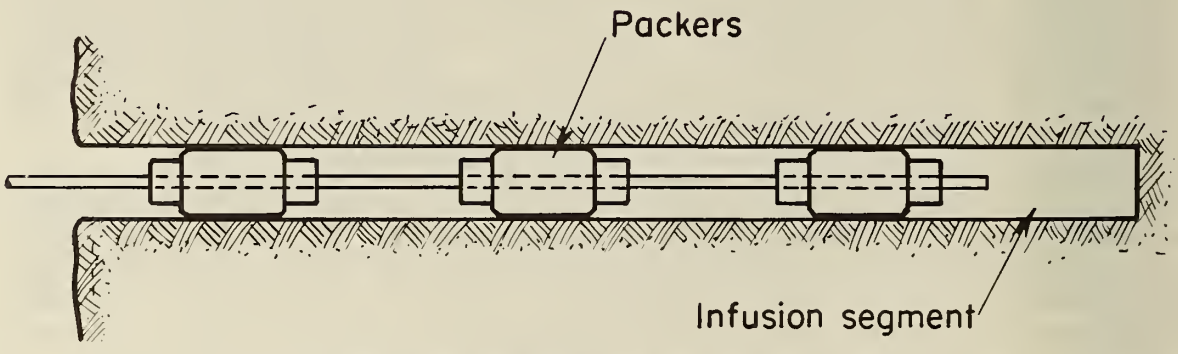


FIGURE 6. - Packed hole for waterflooding.

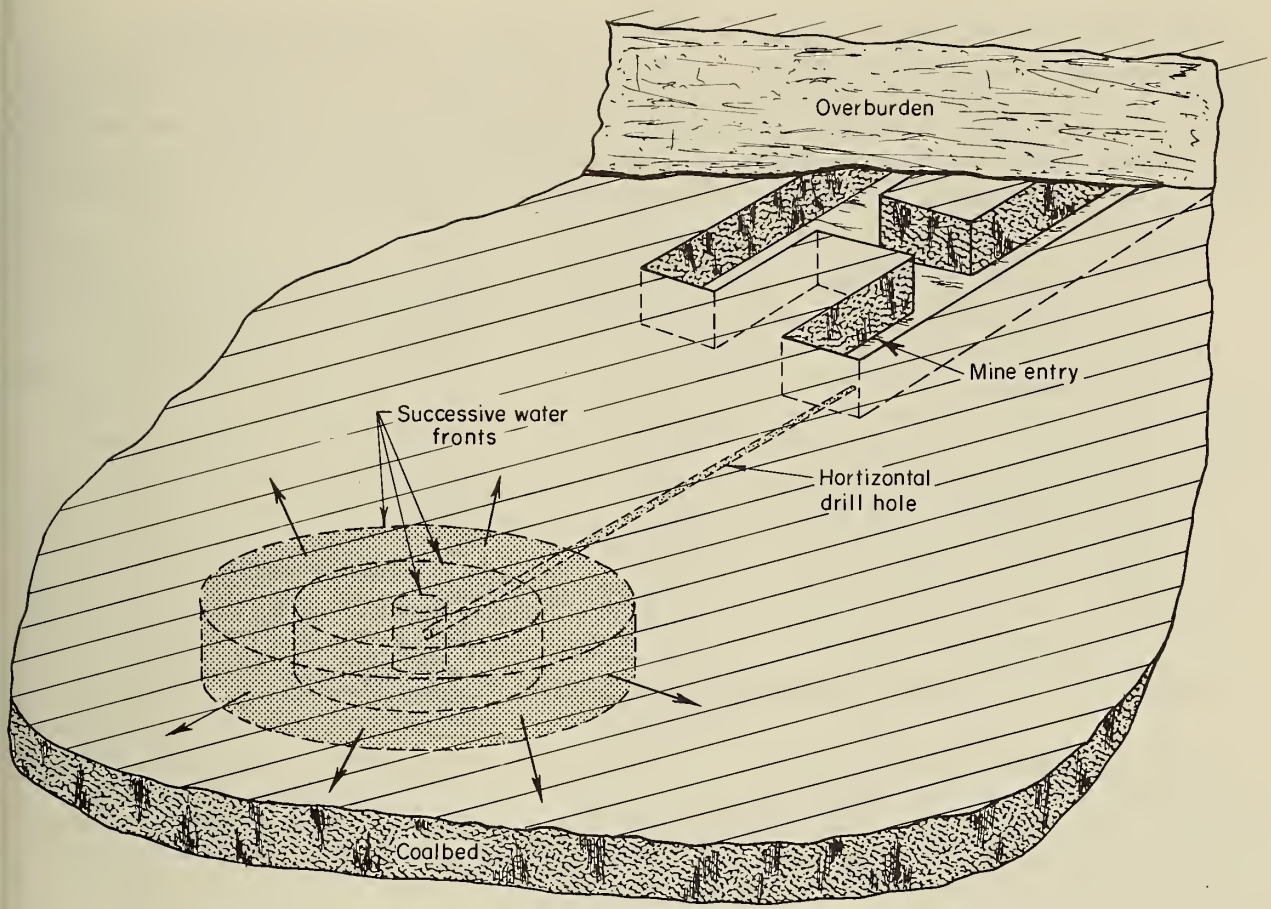


FIGURE 7. - Water infusion of coalbed through a horizontal hole.

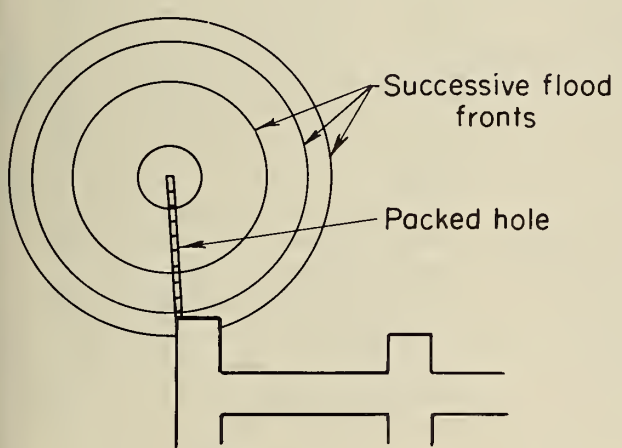


FIGURE 8. - Plan view of infusion through a horizontal hole.

four holes to produce a continuous water bank across the width of the section (fig. 9). All holes are angled a few degrees off the projected development of the entry. Mining into an infusion hole does not create an unsafe condition. Flow from the hole will be water.

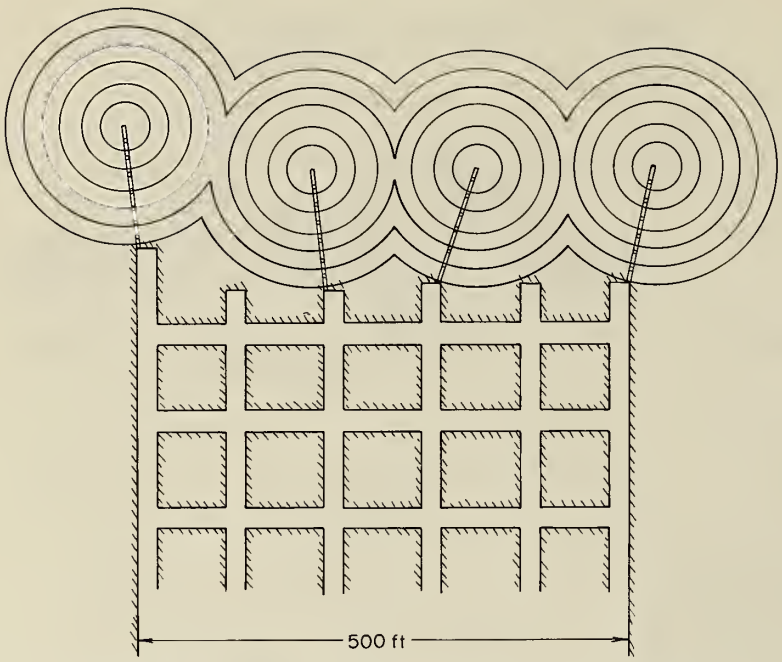


FIGURE 9. - Waterflooded section (125-foot holes).

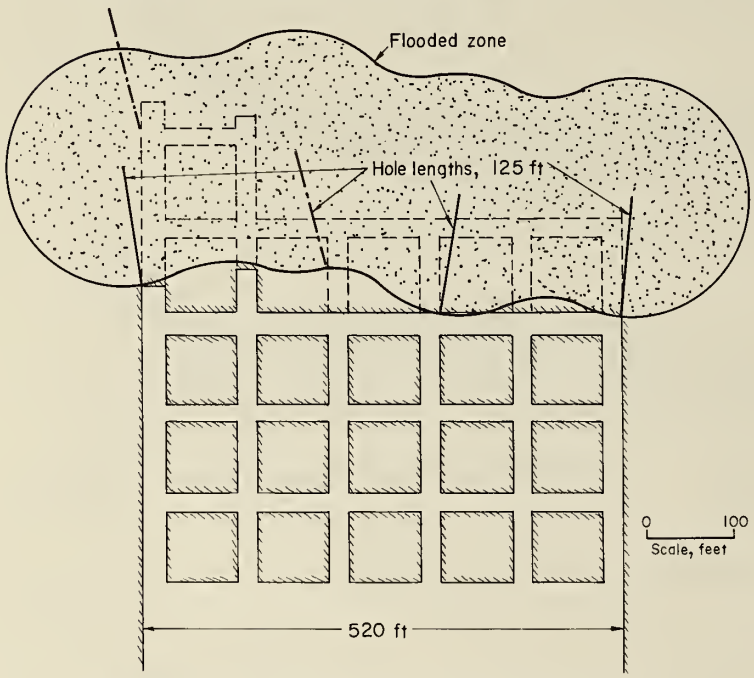


FIGURE 10. - Mining through infused zone.

Mining through an infused zone is shown in figure 10. When a section is flooded through holes drilled to 125 feet, the flooded zone is about 220 feet deep and spans the width of the section. Starting on the left side of the section, two entries are advanced in increments alternately to 100 feet, and the crosscut between these entries is driven in increments also. The continuous miner continues this cycling across the section until the section has been advanced one break, or about 100 feet. The miner then moves to the left side of the section and begins to advance the section on the second 100-foot increment. Mining at this point is still within the flooded zone. However, the hole-drilling and infusion phases should be repeated as the continuous miner completes driving entries and crosscuts on the left side of the section. When the miner completes the advance on the right side of the section and moves back to the left side, the left side has been reflooded and the hole-drilling and infusion phases are completed on the right side. No serious problems exist in integrating the drilling and infusion phases into the mining cycle, and no production delays occur.

The initial flooding of the section should be conducted over a weekend to avoid possible methane problems. Thereafter, the drilling and infusion phases are incorporated into the mining cycle.

The quantity of water infused on a 500-foot development section is about 25,000 gallons. This large quantity of water amounts to about 1 to 2 gallons per ton of coal, which is insignificant when one considers that coal is being sprayed with water during mining at a rate of 40 gal/min. Measurements on the spray system of a shearer showed an average water consumption of 6 gallons per ton of coal and an average of 7.5 gal/ton on a continuous miner.

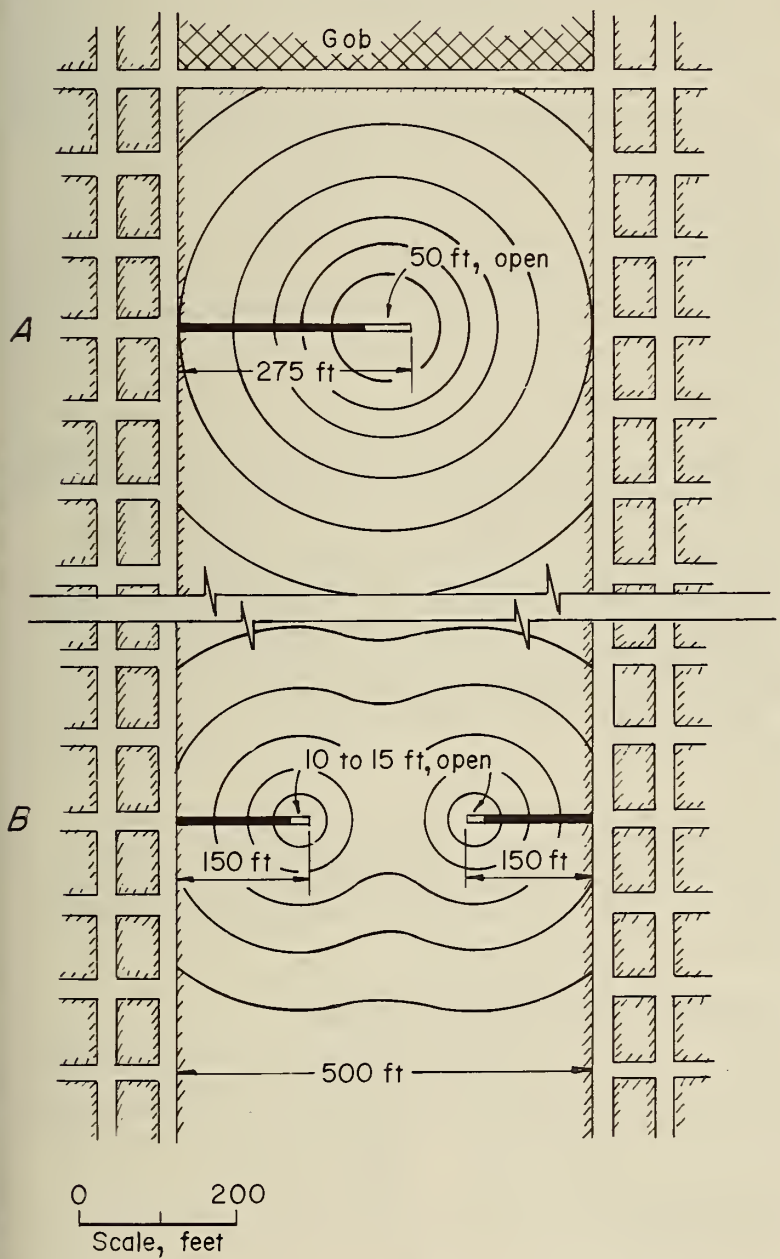


FIGURE 11. - Infusion of longwall with *(A)* one hole and *(B)* two holes.

Infusion in a Retreating Longwall

Unlike a development section, a retreating longwall can be infused with one or at most two holes drilled from the rib sides of the panel. The mechanics of infusion and the spread of water through the panel follow much the same concepts discussed previously for the developmental section.

The procedures for infusing the panel with one hole drilled from the rib side follows (fig. 11A). For a 500-foot panel, the hole is drilled to a depth of about 275 feet, which is about 25 feet beyond the centerline of the panel. Plastic pipe is grouted into the hole to approximately 225 feet, which leaves about 50 feet of open hole for infusion of the panel. When completely unfused, water will have traveled about 225 feet to the left and right of the hole and to both ribs of the panel. The total quantity of infused water will be about 15,000 gallons per foot of coalbed height. Fracture porosity of the coalbed is assumed to be 1 percent. The adjacent hole should be

spaced approximately 400 feet or less from the infused hole for the two flooded zones to merge.

An alternative is to drill and infuse from both sides of the panel (fig. 11B). These holes are drilled to a depth of 150 feet, and plastic pipe is grouted to a depth of 135 feet. When both holes are infused, the flood zones from each hole will merge, and water will have spread about 135 feet to the left and right of the holes. The adjacent pair of holes should be located about 200 feet outby the infused holes.

Short holes, drilled and infused from both sides of the panel, are recommended. Long holes are difficult to drill because they may terminate in the roof or floor rock prematurely. Grouting is more difficult because the grout may set prematurely in the longer hole. The disadvantages of drilling from both sides are (1) power may not be available on both sides of the panel, and (2) drilling space is limited because of the conveyor belt. However, both disadvantages can be eliminated by drilling during the development of the panel.

DUST STUDIES

Several water-infusion studies have been conducted, but not all have been successful. In two tests (York Canyon and Mary Lee coalbeds) water was channeled through large fractures and short circuited to the mine opening. In both cases, the infusion area was associated with tectonic activity such as faulting, slickensides in roof rock and coalbed, and thickening and thinning of the coalbed. In other tests in the Pittsburgh and Upper Freeport coalbeds, valid conclusions could not be drawn because of large variations in dust measurements. However, several tests have been successful. In the successful tests, the infused water contained a wetting agent, although the role of the wetting agent is not known.

Table 1 shows the results of an infusion test in a development section in the Upper Kittanning coalbed. Dust was reduced 25 percent even though production increased 63 percent. If the data are corrected for the increase in production and air velocity during the post-infusion sampling, the dust reduction owing to water infusion is about 50 percent.

TABLE 1. - Infusion of development section

	Average dust concentration, MRE mg/m^3 [1]	Average production, tons/shift	Average air velocity, ft/min	Reduction (normalized), percent
Preinfusion.....	2.4	67	332	
Post-infusion....	1.8	109	397	50

[1]Mines Research Establishment equivalent.

Table 2 shows the results of infusion tests on a longwall in the Pocahontas No. 3 coalbed. Both tests on the longwall show an 81-percent dust reduction in the infused zone. However, if the data are corrected for lower

tonnage during the post-infusion sampling, the dust reduction is 79 and 69 percent for tests 1 and 2, respectively.

TABLE 2. - Infusion of longwall

	Dust concentration, MRE mg/m^3 [1]	Production, tons/shift	Average air velocity, ft/min	Reduction (normalized), percent
Preinfusion.....	9.6	2,104	450	-
Post-infusion 1.	1.8	1,900	450	79
Post-infusion 2.	1.8	1,260	450	69

[1]Mines Research Establishment equivalent.

DRILLING EQUIPMENT

Coal is a soft, brittle material and presents no special drilling problems. Holes are drilled with two types of 3-inch bits. One is a three-blade drag bit (fig. 12) and the other is a roller-cone bit (fig. 13); the latter is used when rock such as a thick slate parting is encountered. Hole trajectory is kept on a fixed course by a 10-ft stabilizer (fig. 14), which tends to prevent hole deviation. The stabilizer diameter is 1/16 inch less than the bit diameter. Returning drill water and cuttings pass back through the annulus between the drill rod and outer barrel (fig. 15).

Holes can be drilled with a handheld air drill (fig. 16) if compressed air is available on the section. This unit has enough power to drill 3-inch-diameter holes to depths of more than 500 feet; it is light (56 pounds) and can be moved from one location to another rapidly. During drilling, the drill is placed on a frame and pushed manually, and pulled out with a "come-along" device. The cost of drilling, grouting, and infusion equipment is approximately $10,000.

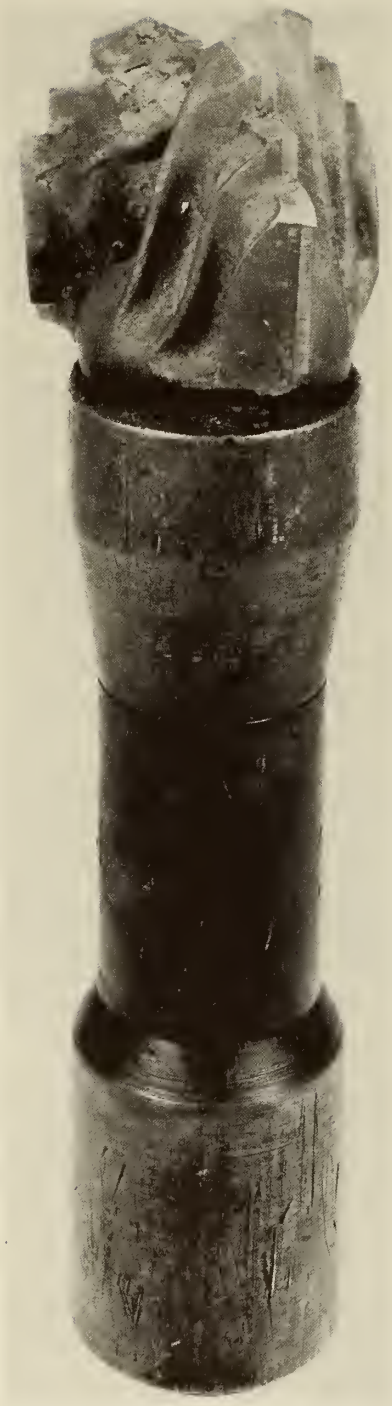


FIGURE 12. - Drag bit.

FIGURE 13. - Roller cone bit.

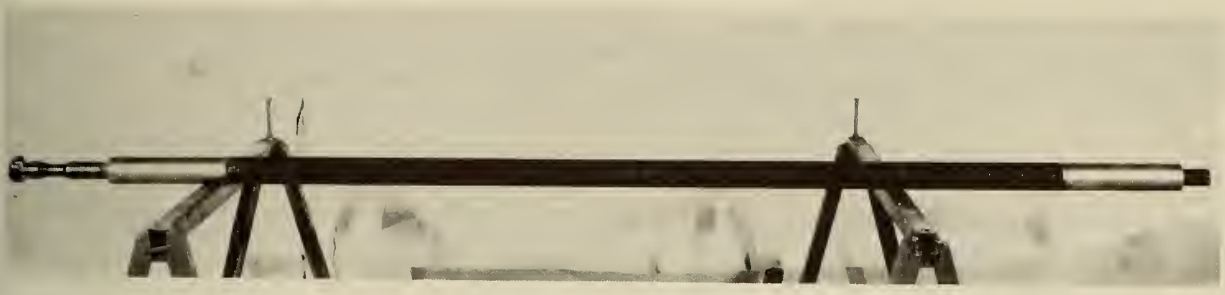


FIGURE 14. - Stabilizer.

FIGURE 15. - End view of 10-foot stabilizer.

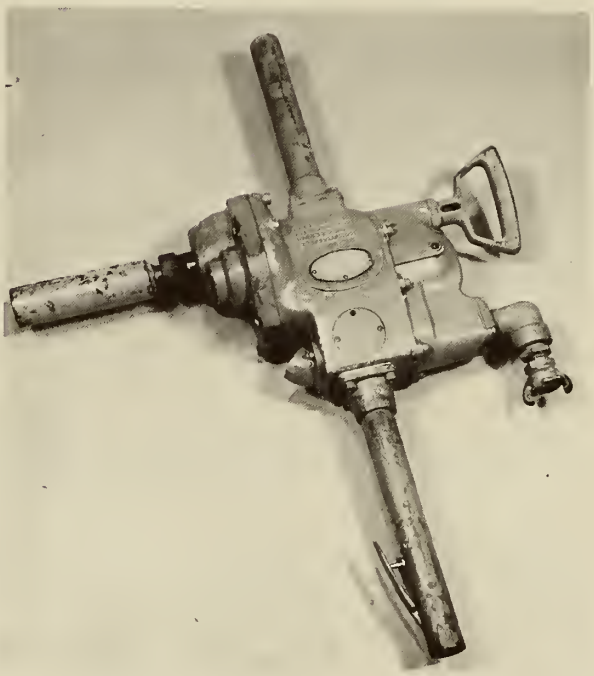


FIGURE 16. - Handheld air drill.

SUMMARY

Water infusion has been demonstrated to be an effective method of suppressing respirable dust during mining in at least two coalbeds.

Investigations of the effect of water infusion on respirable dust are continuing. The technique does show promise and it is used widely in Europe. Considering the small quantity of water infused (1 to 2 gal/ton), the effect on dust generation during mining is significant.

Water infusion will by no means eliminate dust problems. However, when used in conjunction with other dust control measures discussed during this

seminar, acceptable levels can be attained. This presentation should aid in designing experiments with infusion. The Bureau is available to conduct tests on longwalls or development sections, or assist in other ways.

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WETHEAD DUST CONTROL

by

Kelly C. Strebig[1]

ABSTRACT

The Bureau of Mines tested the wethead technique of dust control on four different commercial mining machines to determine whether this method can reduce harmful levels of respirable dust. The in-mine tests were conducted with several different nozzle placements. The wethead technique effectively reduced the dust levels with all four machines without water accumulation on the floor. In addition, the water in the coal reduced dust problems during loading and transportation.

INTRODUCTION

The Bureau of Mines has a multifaceted program in respirable dust control designed to help the coal industry comply with the maximum dust levels allowed by the Federal Coal Mine Health and Safety Act of 1969. The wethead technique uses rotary water seals and a water-distribution system in the rotating cutter drum or auger to bring water to nozzles located on the drum or auger. The water wets the coal while it is being broken so that most of the respirable dust is agglomerated before it becomes airborne. This paper describes the results of in-the-mine tests of three types of continuous-mining machines and a longwall shearer using the wethead technique of dust control.

TESTS AND RESULTS

Tests have been completed with auger- and drum-type continuous miners and a longwall shearer. To evaluate the wethead performance, respirable airborne dust samples were collected at various points in a regular mine production section.

Airborne dust samples were collected for the machines operating "wet" where water was piped through rotating seals to the cutters themselves, and also where the wethead feature was turned off and only conventional fixed sprays were operating. It should be noted that all dust levels are for time on the section and are not portal-to-portal samples.

Tests on a Wilcox Mark 20 auger continuous miner (fig. 1) were conducted in Virginia in the Upper Bolling coalbed (fig. 2), which averaged 38 inches thick at the test site. During the conventional tests, 11 nozzles were spaced across the front of the auger frame and aimed toward the face. The first rotary water seal used (fig. 3) was a large-diameter hub seal that was easily retrofitted to the machine.

[1]Mining engineer, Twin Cities Mining Research Center, Bureau of Mines, Twin Cities, Minn.

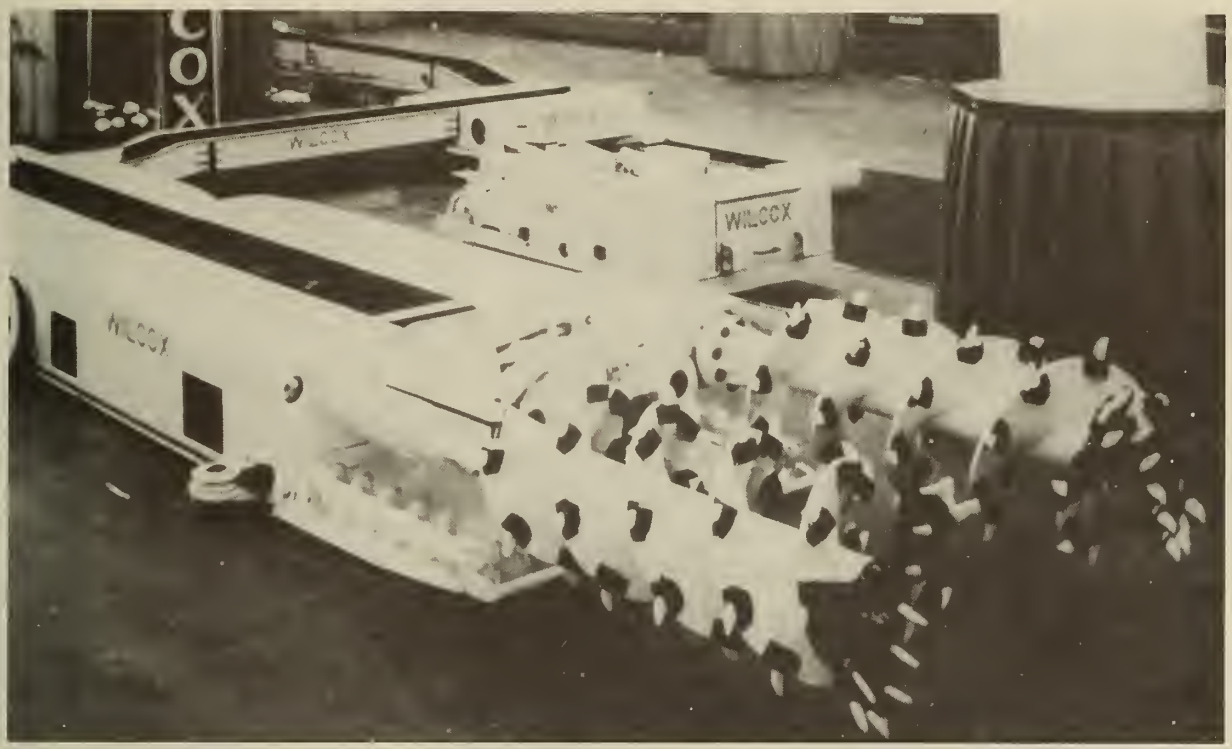

FIGURE 1. - Wilcox Mark 20 auger continuous miner.

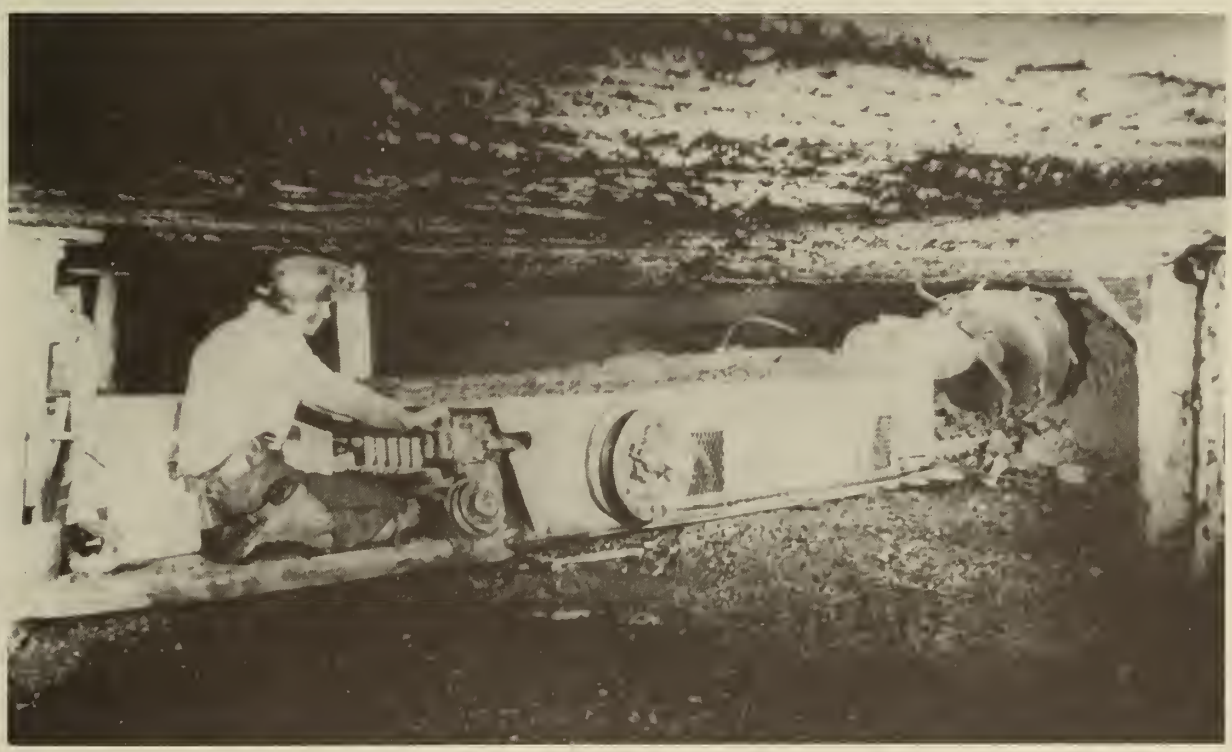

FIGURE 2. - Wilcox continuous miner underground.

The second system (fig. 4) used a small-diameter O-ring, and the water passed through the gearbox. This through-the-gearbox system has the advantage of longer seal life, lower cost, and ease of seal replacement; however, gearbox disassembly is required for system installation. The purchase price of this system is $2,300 for the hollow screw shafts, swivel union, and accessories. The cost does not include the augers. As shown in figure 5, the regular augers can be easily converted by drilling and tapping holes for nozzles into the auger shafts.

During the wet-auger tests, three nozzles were used across the front of the auger frame and six nozzles were spaced around each of the two augers. Respirable dust levels at the high-risk occupation (return-side jacksetter) were reduced 56 percent, and dust levels in the return were reduced 60 percent with the wet augers. When the data are statistically normalized for

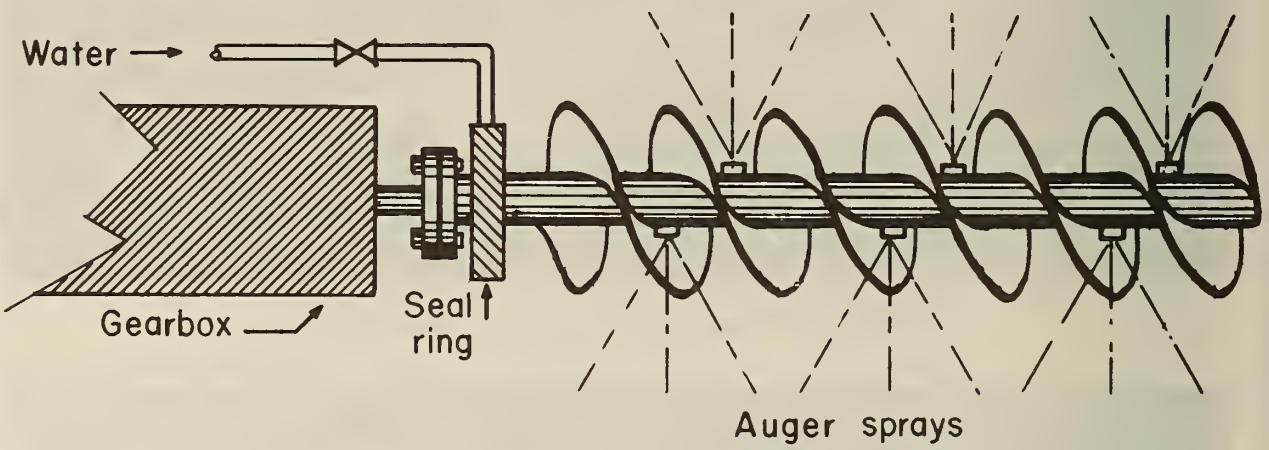

FIGURE 3. - Diagram showing the hub water seal.

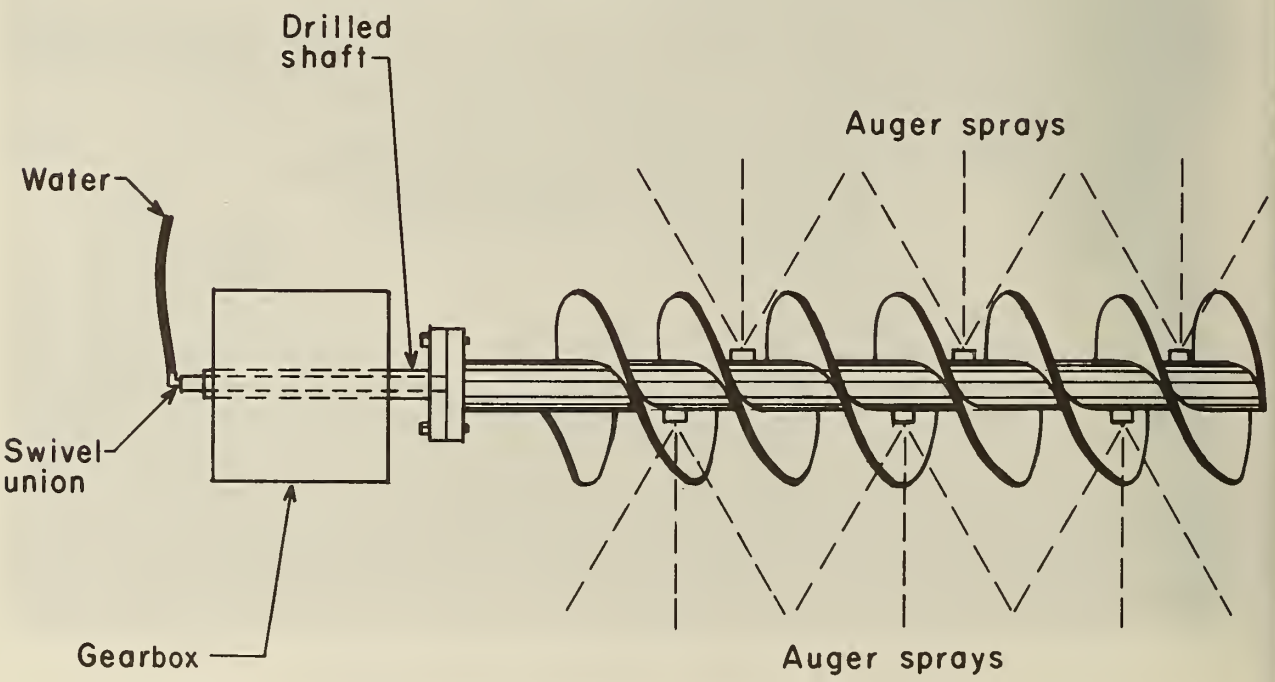

FIGURE 4. - Diagram showing the through-the-gearbox water seal system.

FIGURE 5. - Wet augers, showing the locations of the nozzles on the auger shaft.

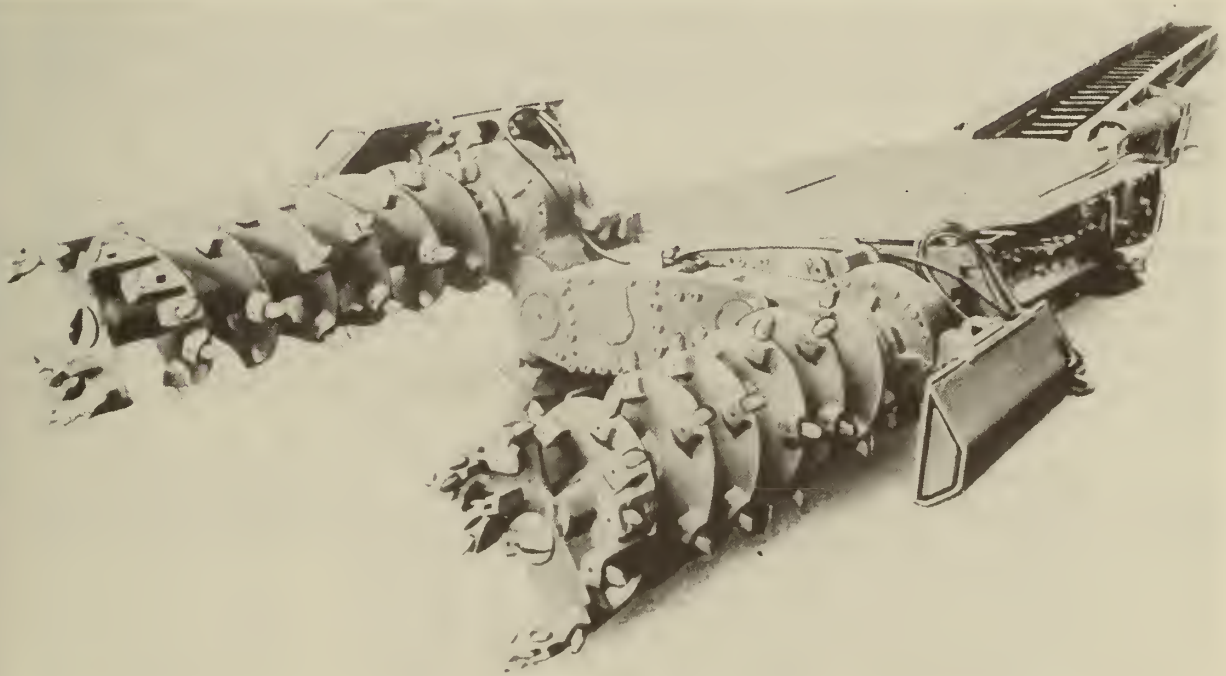

FIGURE 6. - Jeffrey 100L auger continuous miner.

production and airflow (dust concentration times airflow times sampling time divided by tonnage), dust is reduced 47 percent.

Tests on a Jeffrey 100L auger (fig. 6) were conducted in a 28-inch seam (fig. 7). A hub seal system (fig. 8) was used, and two nozzle locations--on the shaft and on the scroll near the bits--were tested. Dust levels at the return-side jacksetter were reduced 47 percent, and dust levels in the return were reduced 46 percent by the use of wet augers with nozzles on the shafts. When the data are corrected for airflow and production, a 36-percent reduction is seen.

Because of leakage problems with the hub seals, a through-the-gearbox water system was developed (fig. 9). This system does require the disassembly of the gearboxes for initial installation, but the seals last longer, do not leak, are very inexpensive, and can be changed in 15 minutes. This system can be purchased for about $7,000.

The Lee-Norse continuous miner (fig. 10) was tested in Pennsylvania in the Pittsburgh seam, which was about 7 feet thick at the test site. The two Lee-Norse 105 Hard Head mining machines used were identical except for their water spray systems. The machines were operated alternately on the same section. The wethead had two sets of nozzles (fig. 11), true-pick-face flushing and a cavity-filling-type system. The cavity filling sprays were located as shown in figure 12. The cavity filling wethead had 40 head nozzles--9 sprays on each of the 2 inner cutters and 11 sprays on each of the 2 outer cutters. When the standard machine was operated in the conventional mode, the 20 boom sprays were utilized.

As shown in table 1, dust levels at the operator and in the return were reduced 50 percent and 17 percent, respectively, by cavity filling. Normalizing for both production and airflow, the wethead method reduced dust levels 24 percent.

The gross airborne dust was reduced 62 percent with the cavity-filling wethead system. On the first machine tested, nozzles were plugged from the inside because of dirty water and contaminants such as rust and metal particles from inside the continuous-mining machine. The problem was solved by filtering the water before it entered the water system on all the miners, and by installing 50-mesh strainer screens under the nozzles where possible. The fluorocarbon seals used in these tests lasted for 15 weeks of two-shift operation before they wore out.

The wethead option on a drum-type continuous miner costs more than $5,000. To change an existing wethead to fluorocarbon seals would cost $700 for seals plus several thousand dollars for seal holders.

TABLE 1. - Summary of data collected underground for evaluation of wetheads

Water systems	Number of shifts	Av production, tons	Av sampling time, minutes	Av water consumption, g/min	Av airflow, ft^3/min	High-risk dust level, mg/m^3	Return			
							Concentration, mg/m^3	Dust, mg/ton	Level, mg (ft^3/min) tons	Reduction in level, percent
WILCOX										
Conventional sprays..	8	158	459	5.9	2,900	8.0	5.0	0.032	1,180	-
Wet auger.....	23	179	422	11.3	4,730	3.5	2.0	.011	620	47
JEFFREY 100L										
Conventional sprays..	9	127	287	10.2	3,100	6.6	7.9	0.060	1,510	-
Shaft nozzles.....	10	132	286	10.8	3,600	3.5	4.3	.030	970	36
Scroll nozzles.....	7	109	249	9.8	3,000	6.3	5.5	.040	1,060	30
LEE-NORSE 105										
Conventional sprays..	6	310	321	25.2	13,400	0.6	1.8	0.006	715	-
Pick flushing.....	12	288	338	26.8	13,800	.7	1.2	.004	531	26
Cavity fill.....	6	306	327	24.3	11,900	.3	1.5	.005	541	24
EICKHOFF SHEARER										
Standard:										
High pressure.....	7	632	NA	26.3	24,100	1.5	8.6	0.014	490	[1]18
Low pressure.....	9	610	NA	20.0	26,500	2.1	10.6	.017	600	-
Front of bits:										
High pressure.....	10	685	NA	27.3	24,700	1.7	8.4	.012	490	[1]40
Low pressure.....	10	677	NA	21.7	26,700	1.8	9.5	.014	810	-
Behind bits:										
High pressure.....	7	631	NA	26.4	23,600	1.1	8.3	.013	550	[1]31
Low pressure.....	9	649	NA	21.9	23,500	1.4	9.2	.014	800	-

NA--Not available.

[1]Reduction is due to higher pressure.

FIGURE 7. - Jeffrey 100L in 28-inch seam.

FIGURE 8. - Jeffrey 100L showing hub seal and nozzle locations.

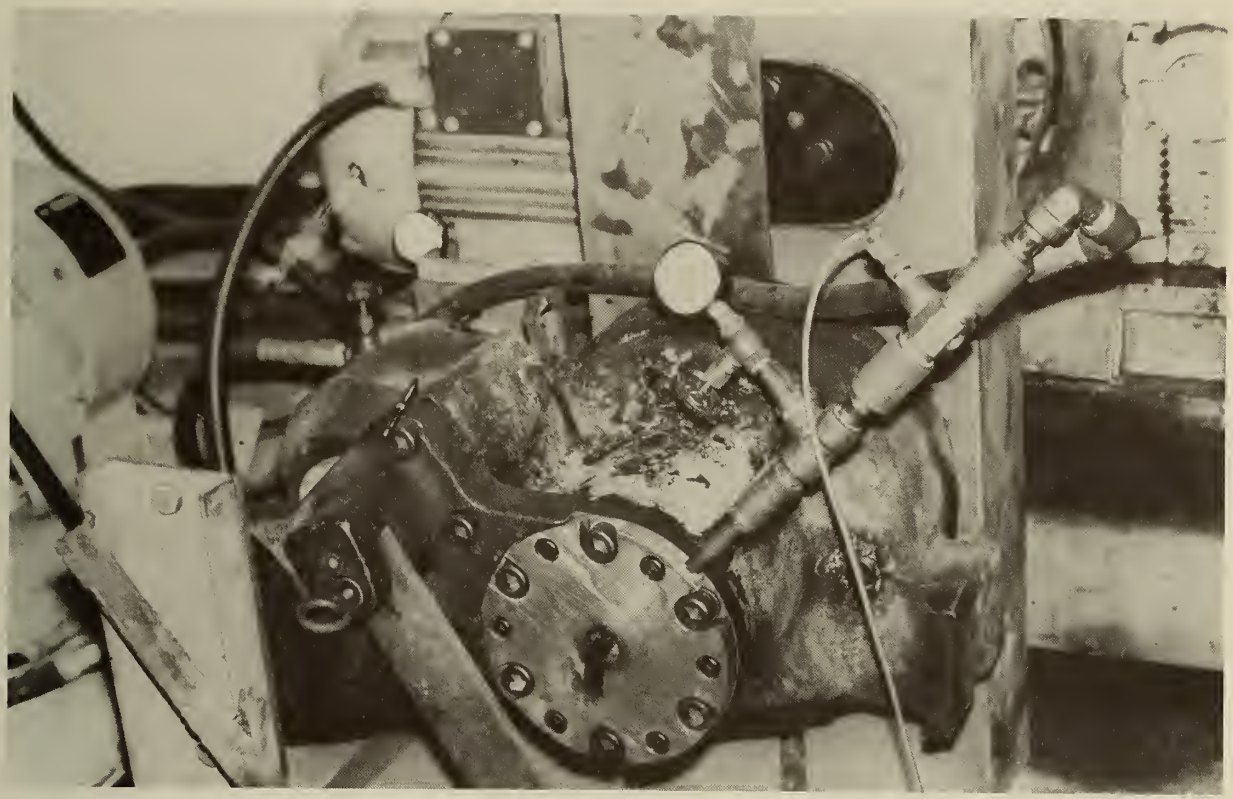

FIGURE 9. - Jeffrey 100L gearbox with through-the-gearbox water system on test stand.

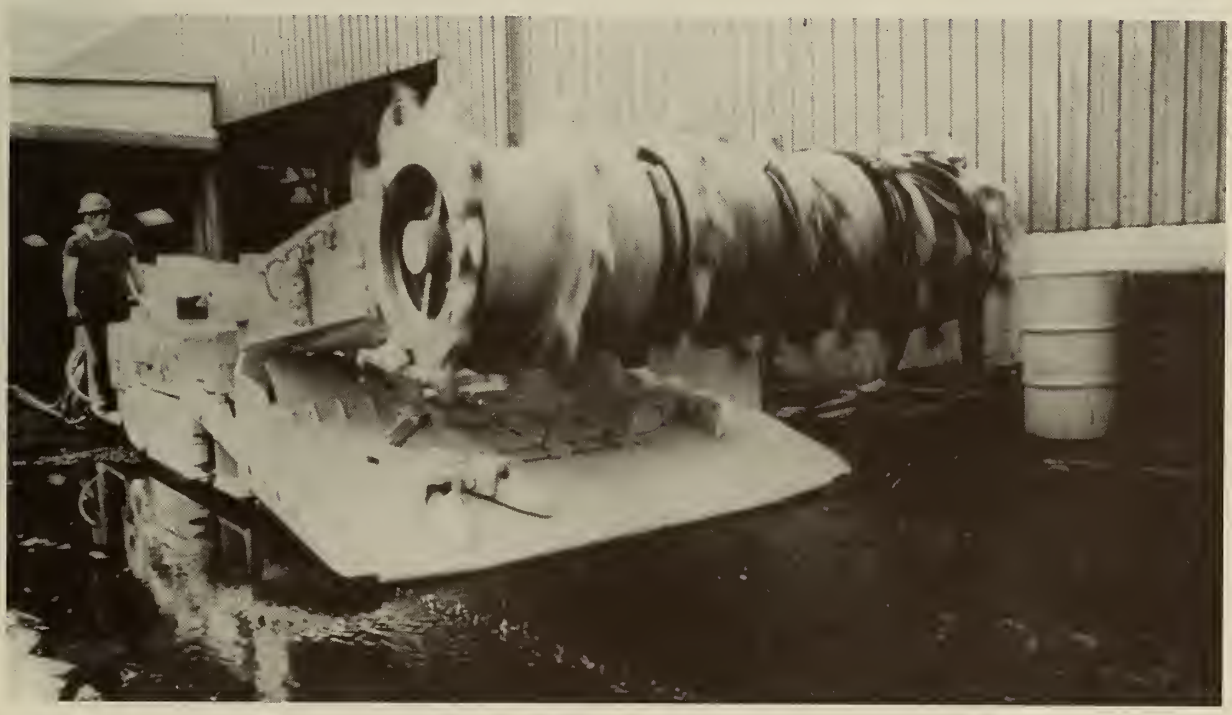

FIGURE 10. - Lee Norse 105 wethead continuous-mining machine.

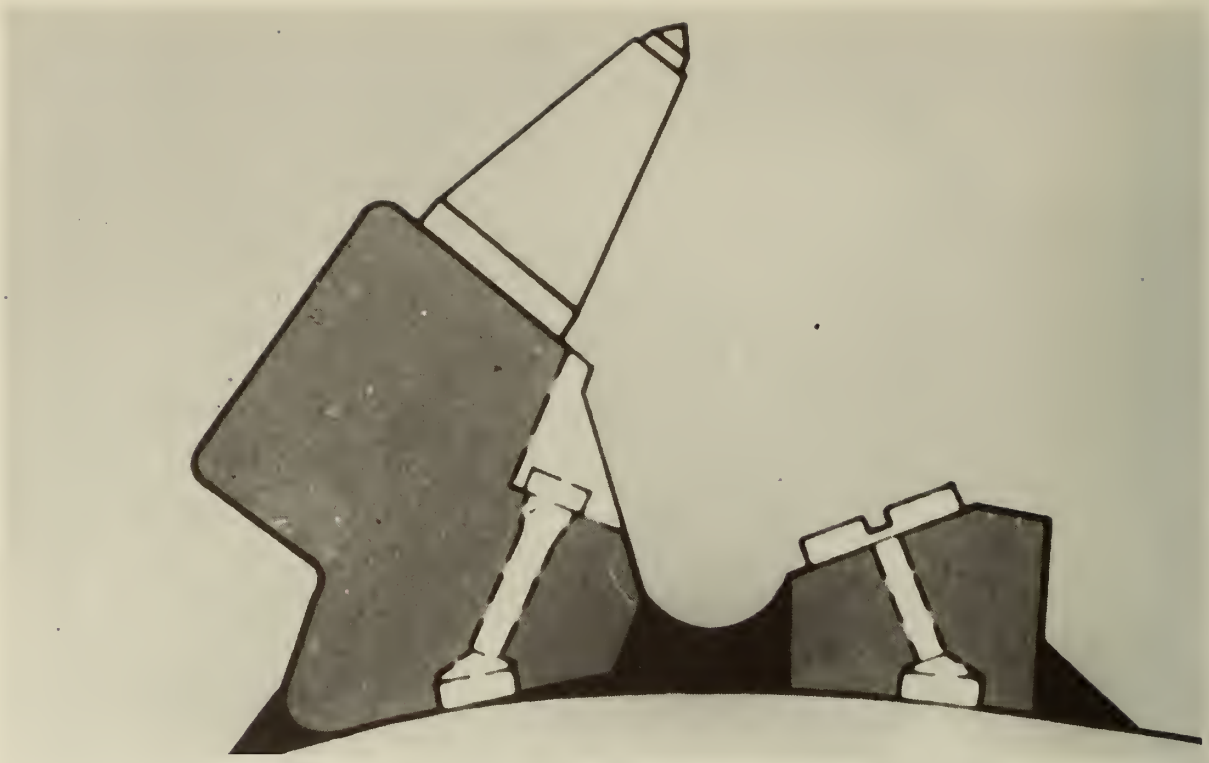

FIGURE 11. - Diagram showing alternate spray locations for Lee Norse 105.

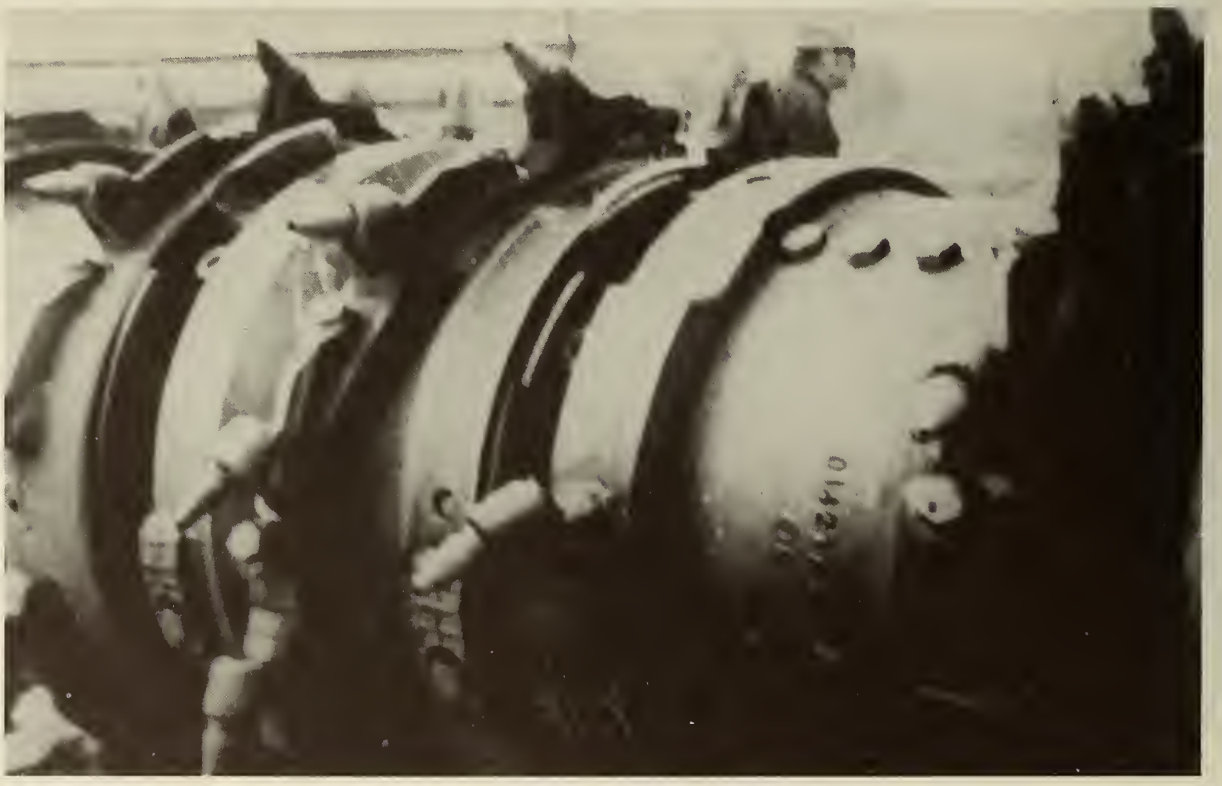

FIGURE 12. - Lee Norse 105 head showing locations of cavity filling sprays.

Tests on the Eickhoff single-drum shearer (fig. 13) were all conducted in the wet-drum mode utilizing three nozzle locations. Like other shearers, the standard Eickhoff drum is a wet drum and has nozzles on the scroll (fig. 14). The other locations tested were in front of and behind the bits (figs. 15-16). There were no significant differences in the dust levels for the three nozzle locations and, since the standard scroll nozzle system is the simplest, that system is recommended. Tests were also run at water pressures of 150 and 250 lb/in^2. The higher pressure reduced the respirable dust 30 percent; therefore, the higher pressure is recommended.

No problems with wet floors resulted from using any of the wetheads because the water was well mixed with the coal and went out with the coal, incidentally helping to control dust at transfer points. Visibility was also improved (figs. 17-18).

FIGURE 13. - Eickhoff single-drum shearer.

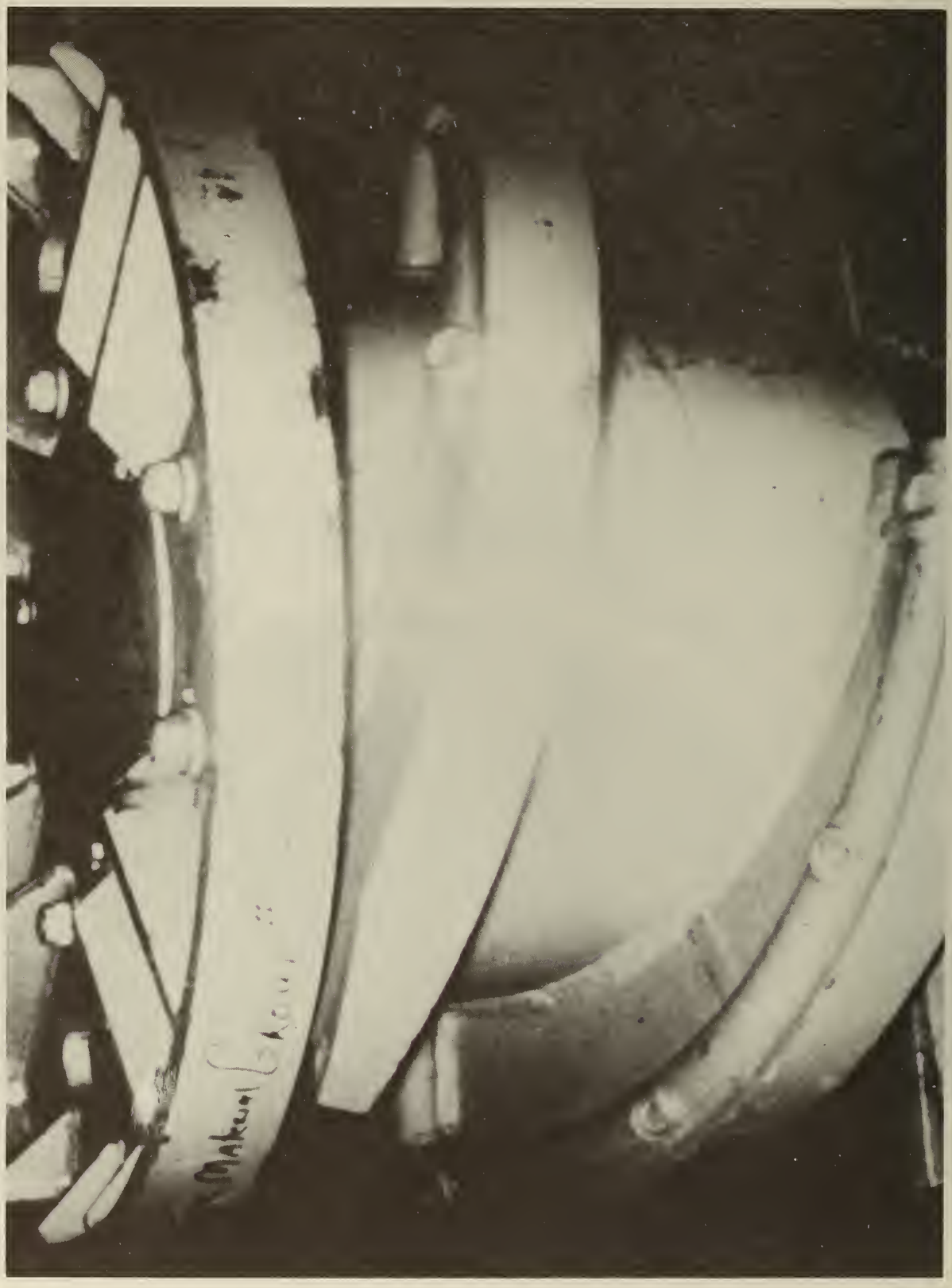

FIGURE 14. - Standard scroll spray system.

FIGURE 15. - Nozzle located in front of bit.

FIGURE 16. - Nozzle located behind bit.

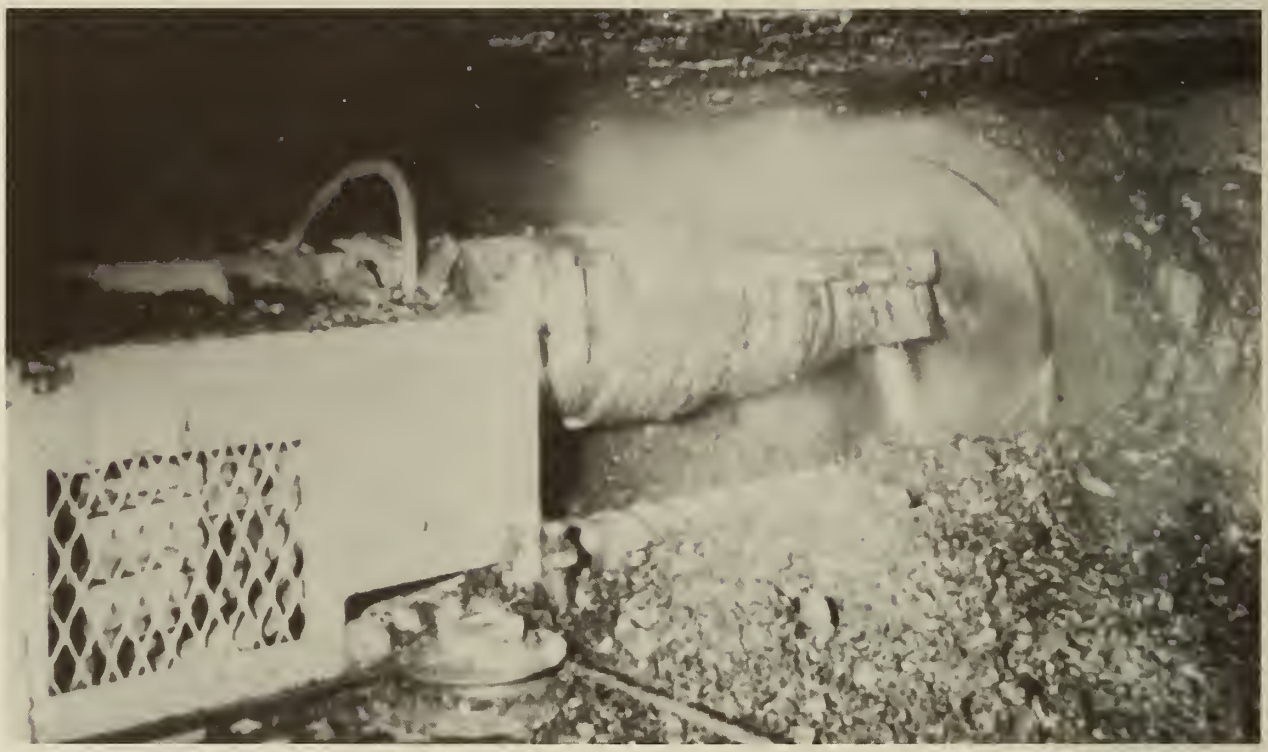

FIGURE 17. - Visible dust without wet augers.

FIGURE 18. - Lack of visible dust with wet augers.

CONCLUSIONS

These four underground tests show that wetheads can reduce respirable dust compared with fixed sprays alone. Wetting the coal while it is being broken controls the dust before it becomes airborne. Greater quantities of water are necessary, however, because the extra water goes out with the coal and does not remain on the floor, incidentally reducing dust problems during loading and transportation.

CONTROL OF RESPIRABLE DUST BY IMPROVED WATER SPRAYS

by

Welby G. Courtney[1] and Lung Cheng[2]

ABSTRACT

This paper reviews the Bureau's progress in developing engineering guidelines to improve sprays used to control dust in coal mining operations.

A nonclogging system developed by a Bureau contractor to replace filter systems in the water line has reduced nozzle maintenance on continuous-mining machines more than 90 percent.

Bureau laboratory research established the optimum characteristics of water spray drops for capturing airborne dust particles and wetting solid surfaces. Using manufacturer's data for drop sizes and velocities, nozzles can be selected for a specific field application by considering the geometry and the airflow pattern at the application. Optimum sprays can be selected from simple, inexpensive nozzles with water line pressures less than 200 lb/in^2.

These laboratory results were then applied to three types of mining operations. At a transfer point, moistening the bottom side of the belt reduced airborne respirable dust 60 percent. At a longwall plow face, new sprays largely eliminated mist, puddles, and drips. At the head of ripper continuous-mining machines, airborne respirable dust was reduced 20 to 50 percent by relocating several of the spray nozzles underneath the cutting boom.

Bureau field tests of foam, steam, and wetting agents are briefly discussed.

INTRODUCTION

One of the main dust control techniques in coal mining operations is water sprays. Sprays have reportedly reduced respirable dust 20 to 60 percent compared with dry operation, although 30 percent seems about average (11).[3] Currently, the type and placement of the spray nozzles are selected arbitrarily because engineering guidelines are not available--a fairly common approach appears to be merely adding more nozzles in the hope of reducing

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[1] Research supervisor.

[2] Mechanical engineer.

Both authors are with the Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

[3] Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

more dust. Techniques seemingly could be devised to use the water more effectively by either greater dust suppression with the existing water flow, or the same dust suppression with a smaller water flow. Water sprays are a relatively inexpensive dust control technique for coal mines, and even a modest improvement in dust control with improved sprays is cost effective.

This paper reviews the Bureau's program for developing such engineering guidelines for improved water sprays and is divided into three sections: (1) Development of nonclogging water system to remove particulate from the water line, (2) laboratory investigation of the interaction between water drops and airborne dust particles or solid surfaces, and (3) field studies of spray effectiveness at the transfer point, and on longwall plows and ripper continuous-mining machines.

To date, the Bureau's program to develop improved water sprays has emphasized conventional spray nozzles at medium line pressures (less than about 200 lb/in^2). This paper also briefly discusses special water sprays and Bureau tests of steam, wetting agents, and foam.

FIGURE 1. - Nonclogging water system.

NONCLOGGING WATER SYSTEM

Although water sprays are a valuable dust control technique, their underground use is limited because the spray nozzles frequently clog in the rugged mine environment. Cleaning or replacing a clogged nozzle is expensive. Usually about one-third of the spray nozzles on a continuous-mining machine clog during a shift, and considerable time is necessary to clean or replace them. In some situations, the plugged nozzles are not serviced at all because operating personnel feel it makes no sense to use production time to service nozzles that will shortly be plugged again. A contract study of the problem (8) indicated that the spray nozzles on continuous-mining machines were clogged by particulate matter in the water line, not by external particles.

Using spray nozzles with larger orifices to avoid clogging is not practical because even larger particulate matter occurs in the water line. In addition, minimized water flow rate often is desired.

Individual filters in each spray nozzle have occasionally been used to reduce clogging. Although this approach works and is especially effective if particulate originates downstream from the conventional filter (that is, if rust or scale is formed inside the machine), burdensome cleaning of the individual filters is still required.

The contractor designed a simple, nonclogging water system to replace conventional spray filters for mining operations. The system (fig. 1) consists of an in-line Y-strainer to remove the plus 1/8-inch rubble, a hydrocyclone to remove virtually all of the remaining particulate material, and a polishing filter to remove traces of particulate matter carried over from the hydrocyclone (mainly during startup and shutdown of the water system). The three components must be installed in the preceding sequence, but can be mounted at any convenient location on the machine. The hydrocyclone can be mounted in any position. Figure 2 shows the system mounted on a Jeffrey Heliminer; in this case, the hydrocyclone was mounted horizontally.

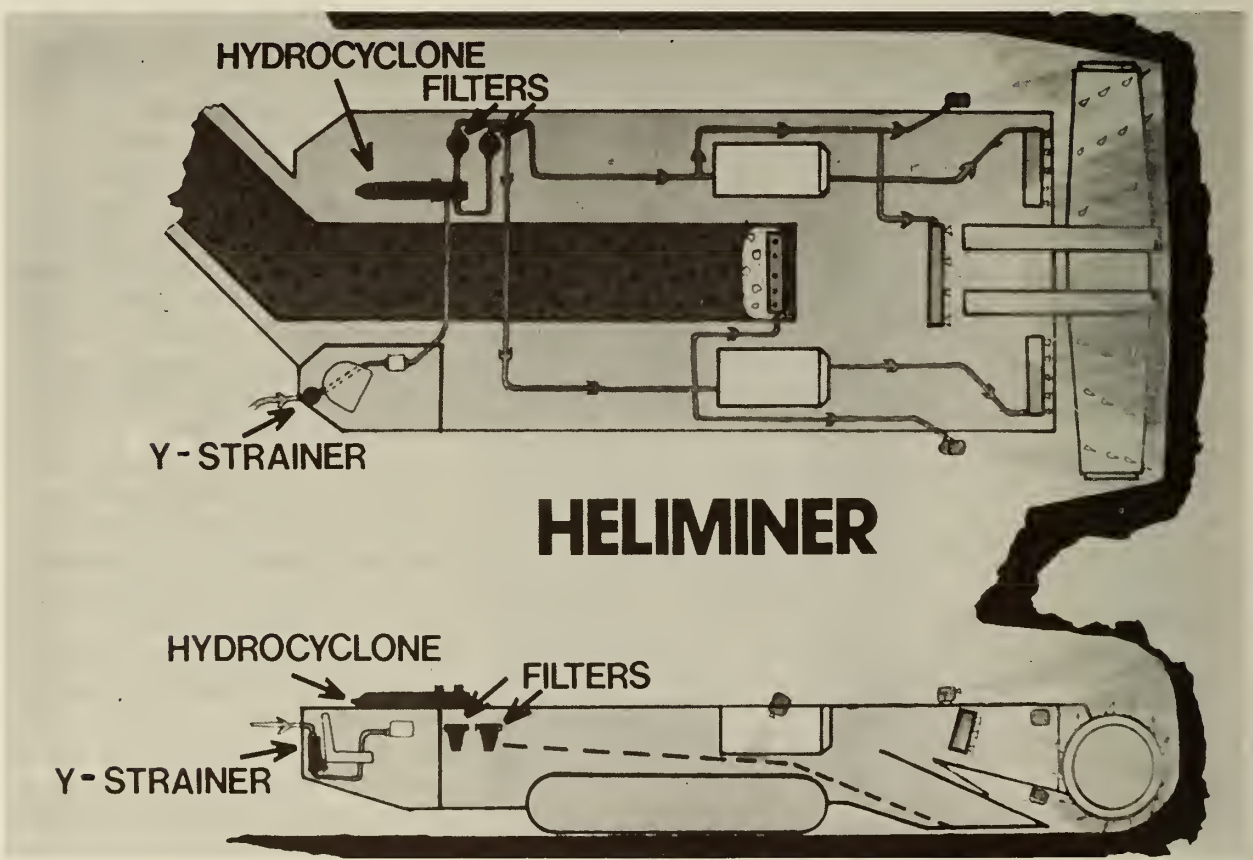

FIGURE 2. - Nonclogging system installed on Jeffrey Heliminer.

The system is flushed about once a week (or more frequently when necessary) by opening the valves on the Y-strainer and the hydrocyclone for a few seconds. Of course, if the system is not periodically flushed and the polishing filter occasionally replaced, the components will eventually clog.

Field tests in underground mines have demonstrated that the maintenance required for sprays on continuous-mining machines decreased more than 90 percent when the new system is used (6). The nonclogging system is available for a total installed cost of under $1,000. Candidate commercially available components are listed in table 1.

TABLE 1. - Components of nonclogging water system

Description	Manufacturer	Approximate cost
Y-strainer, 250-pound rating, screwed connections, stainless steel screen with 1/8-inch-diameter perforations.	Mueller fig. No. 11 or equal from local suppliers.	$25.00
Hydrocyclone, 3-inch-diameter rated for 15 to 40 gal/min. Pressure drop is only 10 lb/in^2 (gage) at 25 gal/min. Pressure rating, 150 lb/in^2 (gage); 300 lb/in^2 (gage) maximum.	Part No. W3U-1260 from Krebs Engineers 1205 Chrysler Dr., Menlo Park, Calif.	385.00
In-line filter (T-type), 300 lb/in^2 rating, approximately 60-mesh stainless steel screen.	Marveline TT (2 units at $120 each) from Marvel Engineering 9227 North Hamlin Ave., Chicago, Ill. 60645	240.00
	or	
	WLF 1KM260-P-D (1 unit) from Schroeder Bros. Corp., Nichol Avenue, McKees Rocks, Pa. 15136	160.00
Miscellaneous items: Flush valves (two), pipe fittings, spare elements, etc.	Local supplier	100.00

LABORATORY RESEARCH

Water sprays can inhibit the formation of dust, immobilize newly formed dust and prevent it from becoming airborne, and collect any airborne dust. Spray parameters to be considered include the size and velocity of the drops in the spray and, of course, the geometry (arrangement and distance) of the

spray. The catalogs published by spray nozzle manufacturers contain a bewildering assortment of spray nozzles and operating conditions, and engineering guidelines for nozzle selection could reduce the time and expense involved in field tests. To this end, the Bureau has been conducting a laboratory research program to establish the optimum size and velocity of water drops for moistening solid surfaces and collecting airborne dust particles.

Dust Formation

No theoretical relationship has been published to express the effectiveness of moisture (water spray drops or steam) in reducing the formation of dust during a cutting operation or in preventing newly formed dust from becoming airborne.

Laboratory study (13-14) investigated the relationship between the total dust-suppression efficiency during a rotary coal-cutting operation and the quantity of water or steam applied at the cutting site. Results indicated that the dust-suppression efficiency of moisture is directly proportional to the amount applied.[4] The maximum suppression efficiency achieved here for respirable-size coal dust was approximately 80 percent. Similar dust reductions were obtained with equivalent amounts of sprayed water drops or steam.

Thus, an appreciable reduction of airborne respirable dust can be achieved if water is added near the cutting site. Steam does not appear to offer any significant advantage over ordinary water sprays in inhibiting the formation of airborne respirable dust.

Impaction

A solid surface is moistened with impacting water drops during cutting and loading at the face, and at transfer points. Moistening depends upon the mass concentration of the drops, the mean drop diameter, and the manner in which the individual drops spread over the surface after impact. Bureau laboratory studies with pure water drops similar to those occurring in conventional medium-pressure sprays indicated that such drops flatten upon impacting a solid coal surface (fig. 3) or even a thickly dust-laden surface (2). The flattening drop sweeps an area about 10 times the area covered by the static, quiescent drop, and scavenges and immobilizes the top layer of dust particles covered by it. A water drop containing wetting agent penetrates into the dust layer and is several times more effective than the pure water drop in immobilizing the dust.

Impact coverage is optimum for drops approximately 500 micrometers in diameter and increases with increasing drop velocity. Manufacturer's data is available for mean drop size, flow rate, and spray angle for assorted nozzles and various line pressures. Thus, for any given mining operation, a spray nozzle can be selected to give the mean drop size for the stipulated degree

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[4]Increased dust suppression with higher water application should of course be expected, just as no airborne respirable dust would form if mining were done in a swimming pool.

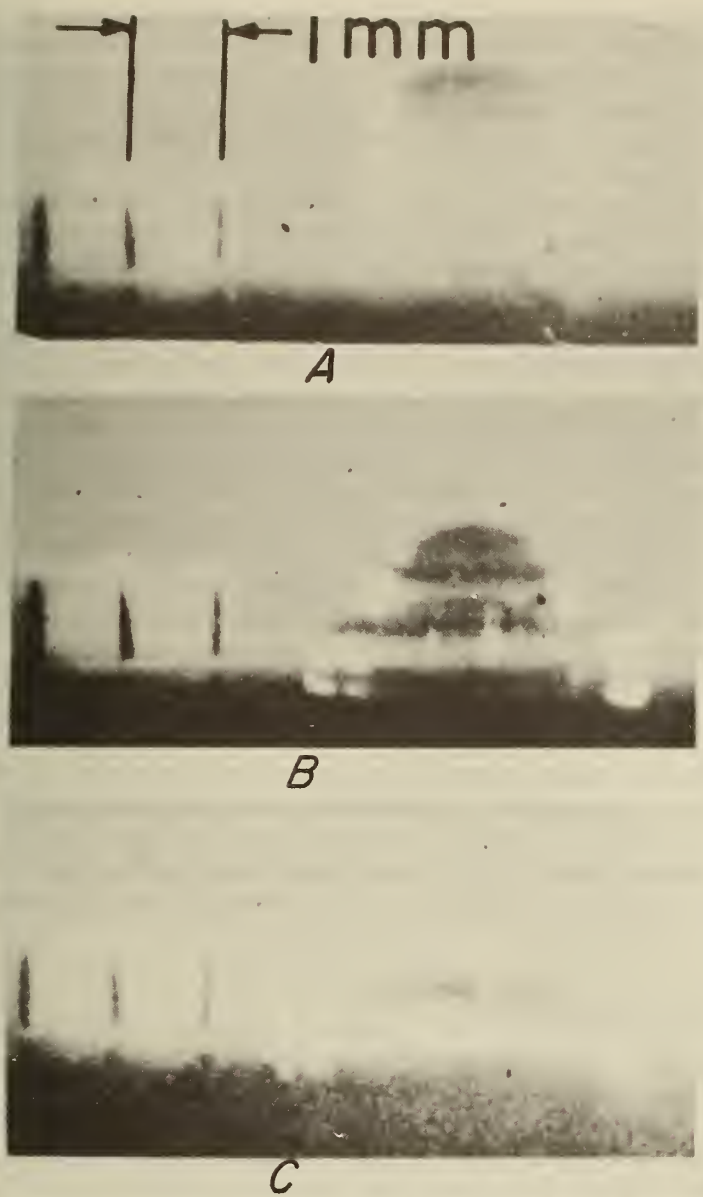

FIGURE 3. - Water drop impacting a coal surface. *A*, 0.0000 sec; *B*, 0.0018 sec; and *C*, 0.0045 sec.

of coverage, line pressure, water flow rate, and geometry. Of course, it is unlikely that a nozzle is available that precisely meets all of the stipulated conditions, so the optimum nozzle must be chosen. A nozzle giving a mean drop size about 40 percent bigger or smaller than the optimum drop size would result in approximately a 25-percent deduction in coverage for the same water flow rate, or would require about 25 percent more water for the same coverage. Alternatively, if the line pressure were doubled, about a 33-percent increase in coverage can be expected, primarily because of the drop size-velocity effect and secondarily because of the increased water flow rate.

Collection of Airborne Dust

In collecting airborne dust particles with water drops, the drop collides with the dust particle, and the particle-drop agglomerate then settles to the floor or is otherwise collected. For respirable coal dust particles, the overall collection efficiency E of the spray is as follows (1):

$$E = 1 - \exp\left(-3\eta L\dot{Q}/2D\dot{Q}_g\right),$$

where η is the fraction impaction (target or capture efficiency) of a single drop with the particles in the dust cloud, and includes the effect of particle diameter; L is a characteristic length for the total capture process and will depend upon the specific operation under consideration; D is the mean diameter; and $\dot{Q}$ and $\dot{Q}_g$ are the volume flow rates of the water and the air in the dust-drop mixture.

Bureau laboratory research (15) has indicated that optimum capture of airborne respirable coal dust particles occurs with ~200-micrometer-diameter water drops for a wide variation in drop velocity.[5] Thus, airborne capture by a conventional medium-pressure water spray can be optimized using (1) manufacturer's data for spray parameters such as nozzle type, line pressure, spray angle, water flow rate, and mean drop size; (2) the geometry of the spray-dust system; and (3) the local airflow pattern, including air entrainment by the spray. Somewhat surprisingly, about 70 percent of the airborne particles can readily be captured by water sprays.

Steam, or a combination of steam and water spray, is a popular dust control technique in the nonmining industries, but no detailed study has reported the usefulness of steam for collecting airborne coal dust. The Bureau, therefore, conducted a laboratory study (4) of the effectiveness of steam and steam followed by water spray for the collection of airborne coal dust. For the same moisture input, the steam-spray sequence was about 14 percent more effective than a water spray alone for respirable coal dust. The steam-spray sequence is particularly effective for small particles. However, steam involves awkward logistics, since water must be heated and the steam later cooled, and thus steam does not appear to be an attractive approach for collecting airborne dust in underground coal mining operations.

The effect of wetting agents in the spray was also examined (4). Three agents were tested--anionic, cationic, and nonionic. The wetting agents reduced the surface tension of water about 50 percent and also reduced the mean drop size in the spray about 50 percent. Laboratory tests indicated that 10 to 15 percent more airborne respirable coal dust can be collected with wetting agents than with water alone. This increase is modest, and the use of wetting agents only to enhance airborne capture would not justify the inconvenience and expense.

Special Sprays

Three types of nozzles not included previously are the venturi-eductor, pneumatic, and ultrasonic.

The venturi system involves passing a conventional water spray down the throat of a small venturi shroud. The air entrained by the conventional spray (approximately 50 to 100 ft^3/min per gal/min) is further accelerated by the venturi configuration, resulting in a high relative velocity between the water drops and the entrained dust particles. Such a system is reportedly very efficient (<90 percent) at collecting airborne dust particles in the entrained airstream (9). The venturi system can also be useful as an air mover for mines.

The pneumatic spray involves mixing high-pressure air with the water in a plenum chamber and then passing the air-water mixture through a nozzle to form a spray of very small drops. The collection efficiency of a pneumatic

[5]More strictly, airborne capture slightly increases with an increase in the particle-drop relative velocity.

spray for airborne dust particles has not been reported but probably is low because the small drops should quickly lose their momentum and give a low relative velocity between the drops and entrained air particles. A pneumatic spray is therefore probably not too attractive for dust collection, particularly since an auxiliary high-pressure air system is required.

A commercially available ultrasonic pneumatic spray uses a specially designed nozzle to generate a shock wave to further atomize the water. Underground field tests with this type of nozzle in a potash mine have reportedly indicated a tenfold reduction in dust compared with dry operation.

Summary of Laboratory Studies

Briefly summarizing at this point, spray nozzles that give high-velocity drops about 200 micrometers in diameter are considered to be best for the airborne capture of respirable dust particles, while nozzles that give high-velocity, ~500 micrometer drops are best for impaction. In practice, however, the geometry of the system and any local airflow are also important. Furthermore, it is sometimes difficult to decide whether airborne capture or impaction is most important for a given situation.

Therefore, while an optimum spray system can be custom designed for a specific situation, the preparation of a complete handbook of spray systems is still in the future, and field research will be required for some systems. In the interim, table 2 gives information for several spray nozzles that are optional for airborne capture or impaction. For example, for a belt conveyor system involving a water spray, impaction is the major dust-suppression mechanism. If the nozzle is 4 feet from the target surface (D = 4 feet) and minimal water is desired, the G3 nozzle should be operated at 30 lb/in^2 and located so that the spray angle of 65° gives proper coverage. If a lesser spray angle is desired and water flow is less important, the G3 nozzle should be operated at 50 lb/in^2. If the nozzle is only 3 feet from the target and a higher water flow is desired, the G3.5 nozzle can be used and operated at 140 lb/in^2. Although the BD nozzles are popular for in-mine use and are included in table 2, they give hollow-cone sprays and are thought to be less effective than are solid-cone aprays because of a lower drop velocity.[6]

An increase in spray efficiency for dust control is not automatically achieved by increasing the line pressure. For example, increasing the line pressure can decrease the mean drop size in the spray to such an extent that the high-pressure fine drops are entrained in the local airflow and never have a chance to play an effective role in dust suppression.[7] In practice, table 2 shows that optimum sprays can be obtained with line pressures of less than 200 lb/in^2 and, depending upon the situation, as low as 30 lb/in^2. Finally, the effect of the environmental air velocity is not included in table 2, but can be important.

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[6]The BD nozzles have a large orifice and thus will be less likely to clog; however, the new nonclogging water system discussed earlier should eliminate clogging with almost any practical water nozzle.

[7]In the extreme case, the fine drops will evaporate and thus merely serve to humidify the environmental air.

TABLE 2. - Optimum spray nozzles for dust control

Distance,[1] feet	Mean drop size, micrometers	Optimum nozzle[2]	Water flow rate, gal/min	Line pressure, lb/in^2	Spray angle
AIRBORNE COLLECTION					
2.5	220	BD	0.95	100	78°
3.5	340	BD5	1.0	40	70°
4.5	240	G3004	.90	200	32°
6	340	G2	.77	150	40°
8	420	G3	1.1	150	50°
10	530	G3007	1.1	100	30°
11	580	G3009	1.4	100	30°
IMPACTION					
2	300	G3004	0.78	160	32°
2.5	470	G2	.56	90	46°
3	480	G3.5	1.2	140	40°
4	880	G3.5	.74	50	48°
4	990	G3	.50	30	65°

[1]Length of the practical system under consideration.
[2]Available from Spraying Systems Co., Bellwood, Ill. These nozzles are included because information on drop size is available.

FIELD APPLICATIONS

Transfer Points

An earlier Bureau study showed that an enormous amount of respirable dust adheres to ordinary run-of-face broken coal (5). Thus, enough respirable dust adheres to 15 points of broken coal to contaminate 1,000,000 ft^3 of ventilation air up to the 2-mg/m^3 level if it were to become airborne. Also, a large amount of dust can adhere to the conveyor belt. The potential of secondary handling operations, such as belt-to-belt transfer, for creating dust is evident.

Bureau research indicates that the dislodgment of the dust adhering to the underside (the non-load-bearing side) of the belt is the major dust source at the field transfer point.[8] Thus, water sprays injected directly into the falling coal reduced the formation of airborne respirable dust only about 10 percent compared with dry operation, while adding water sprays under the belt reduced airborne dust 60 percent compared with dry operation.[9]

[8]Other Bureau work (3) indicated that only about 10 percent of the dust adhering to dry broken coal is dislodged and becomes airborne during a typical drop operation, while the formation of new dust due to fracture of the run-of-face broken coal was negligible. About 30 percent less dust is dislodged by decreasing the drop height or slowing the belt by a factor of 2. These laboratory conclusions have not yet been tested in a full-scale field operation.
[9]Other field tests at an iron ore belt transfer point indicated a 90-percent reduction in airborne dust when the underside of the belt was moistened.

Similar field tests indicated that low-expansion foam on the underside of the belt reduced dust 80 percent compared with dry operation (13). Although foam was about 50 percent better than conventional water sprays, its inconvenience and expense (about 5 to 10 cents/ton) may limit its use in the field.[10]

Various dust enclosures and collectors for transfer operations have been examined at processing plants for several years and are reportedly quite successful. Underground mining operations require a smaller and more mobile enclosure-and-collector assembly. Such an assembly should be effective, but it must be carefully designed and can be expensive (about $10,000 installed cost).

Although excessive belt wear or physically uncomfortable conditions in the mine environment can result from excess water, improved dust control at a transfer point can be achieved by--

1. Installing the nonclogging water system,

2. Moistening the underside of the belt (either with water sprays or a trickle device such as moist canvas).

If additional dust control is required,

3. Improved water sprays located somewhat upstream of the discharge point can be used to moisten the broken coal on the belt,

4. Drop height can be minimized, and

5. An inclined chute can be used instead of a vertical drop.

Finally, if still additional dust control is required,

6. Foam or an enclosure-and-collector assembly can be considered.

Longwall Plow

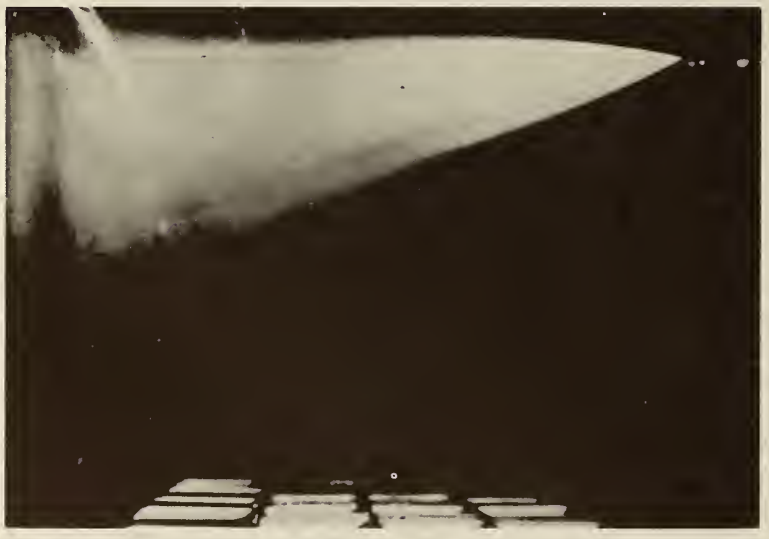
A current Bureau contract by Bituminous Coal Research, Inc., is improving water spray systems for a longwall-plow mining operation. The existing water sprays (two RD3 nozzles per chock, 150 lb/in^2 pressure at the nozzle, and a booster pump) were causing problems: Water dripped from the chocks, puddles formed on the floor, and there was heavy mist in the ventilating airstream. Eliminating the booster pump reduced the line pressure at the nozzle to 70 lb/in^2, but did not significantly alleviate the problems.

A brief laboratory study to select an improved water-spray system for the plow face used a full-scale simulated face. The previously noted laboratory impaction work provided engineering guidance for selecting the nozzle type and line pressure. In this case, the ventilation air velocity was high enough to affect the geometry of the spray. With the mine spray system, the

[10]Refoaming in the washing plant also can occur.

laboratory results indicated that more than 30 percent of the mine water was being wasted as mist. With most of the candidate nozzles, about 25 percent of the water usually ended up as mist when the nozzle was operated at 150 lb/in^2 line pressure. The laboratory study further indicated that single, chock-mounted G3009 nozzles operated at 70 lb/in^2 (no booster pump, directed at the face but angled at 45° in the direction of the ventilation airstream) gave good face coverage and only 2 percent mist. Figure 4 shows the coverage achieved with the mine BD3 system and the recommended G3009 spray system.

A



B

FIGURE 4. - Water sprays on longwall plow face. *A*, BD3 nozzle, 150 lb/in^2; and *B*, G3009 nozzle, 70 lb/in^2.

In a subsequent field study (under the same contract), the new G3009 spray system eliminated the drips and mist and reduced the puddles. The new system also eliminated the inconvenience and expense of a booster pump. Field studies are currently underway to determine whether the G3009 spray system also reduces respirable dust.

Ripper Continuous-Mining Operations

One of the main dust control techniques used with ripper continuous-mining machined is water sprays mounted on the top of the cutting boom. Applying the laboratory results on airborne capture and impaction to ripper mining operations is difficult because of the chaotic airflow patterns at the cutting boom, the variety of cutting operations (sump or shear, box or slab), and the variety of dust sources at the boom (cutting or loading).

In view of the necessity of improving water sprays as rapidly as possible, and the complexity of the phenomena involved at

the cutting boom, the Bureau has begun to explore dust sources and the importance of nozzle type and location at the cutting boom. The general approach was to compare the amounts of respirable dust escaping from the face into the return with different nozzle locations and parameters.[11] Four field studies have been conducted to date with coal seams about 6 feet high.

For dust sources, results indicated that (1) about 70 percent of the respirable dust that escapes the face area is generated during the sump cut, about 20 percent during the shear cut, and about 10 percent during the loading operations; (2) the slab cut permits more dust to escape the face area than the box cut; and (3) a deep box cut permits less dust to escape than a shallow box cut. Thus, emphasis was given to the influence of water sprays on the sump operation.

Results of field testing various spray locations are somewhat mixed to date and appear to depend upon the type of mining machine and perhaps the moisture content of the coal. For example, with a Lee Norse 26H and moist coal (5 percent), the tests (12) indicated that water sprays conventionally mounted on the top of the boom allowed 22 percent less respirable dust to escape the face area during a sump than during dry operation. Sprays mounted under the boom and directed downward onto the broken coal reduced the respirable dust 50 percent. Thus, a reduction of about 40 percent was achieved with bottom sprays compared with top sprays. Conventional top sprays and bottom sprays conventionally directed toward the face were equally effective in the sump operation of a Lee Norse 456 on damp coal (3 percent water); in the shear operation, the bottom sprays were about twice as effective as the top sprays.

With a Jeffrey Heliminer and dry coal (2 percent), top and bottom sprays reduced the sump dust about 50 and 20 percent, respectively, compared with dry operation. The top location for the spray is thus preferred in this case, although bottom sprays still contributed to improved dust control.

One series of field tests has been conducted to date to investigate the effect of nozzle type (7). With a Lee Norse 26H, G3004 nozzles at the conventional locations used one-third less water with only a 15-percent increase in dust compared with the John Bean nozzles used by the mine. Thus, if a section in compliance were encountering a moisture problem (owing, for example, to a soft bottom), some improvement may be achieved with improved water sprays.

It should be noted that a high line pressure is not necessarily the best alternative. Figure 5 shows the spray pattern at the front of the Lee Norse 26H with and without the booster pump. The line pressure at the spray nozzles is about 70 lb/in^2 with the booster pump compared with 15 lb/in^2 without the pump. While the pump obviously increases the water flow, an

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[11] Despite the complex phenomena at the cutting boom, laboratory studies of airborne capture and impaction were used to guide the selection of nozzle type and line pressure to select widely different nozzles, not with the expectation that airborne capture or impaction would be solely important.

appreciable amount of this increase is being dissipated as mist and therefore making no contribution to dust control.

Thus, although the bottom nozzle location has improved dust control in most cases, and further improvement can be achieved by selecting new types of nozzles, additional work is required before definite conclusions can be presented. The Bureau plans to continue field studies to determine the role played by water sprays during cutting at the face. In the interim, relocating about one-half the sprays from the top of the cutting boom to beneath the boom, and directing the bottom sprays downward onto the broken coal should offer a significant improvement in dust control in most cases.

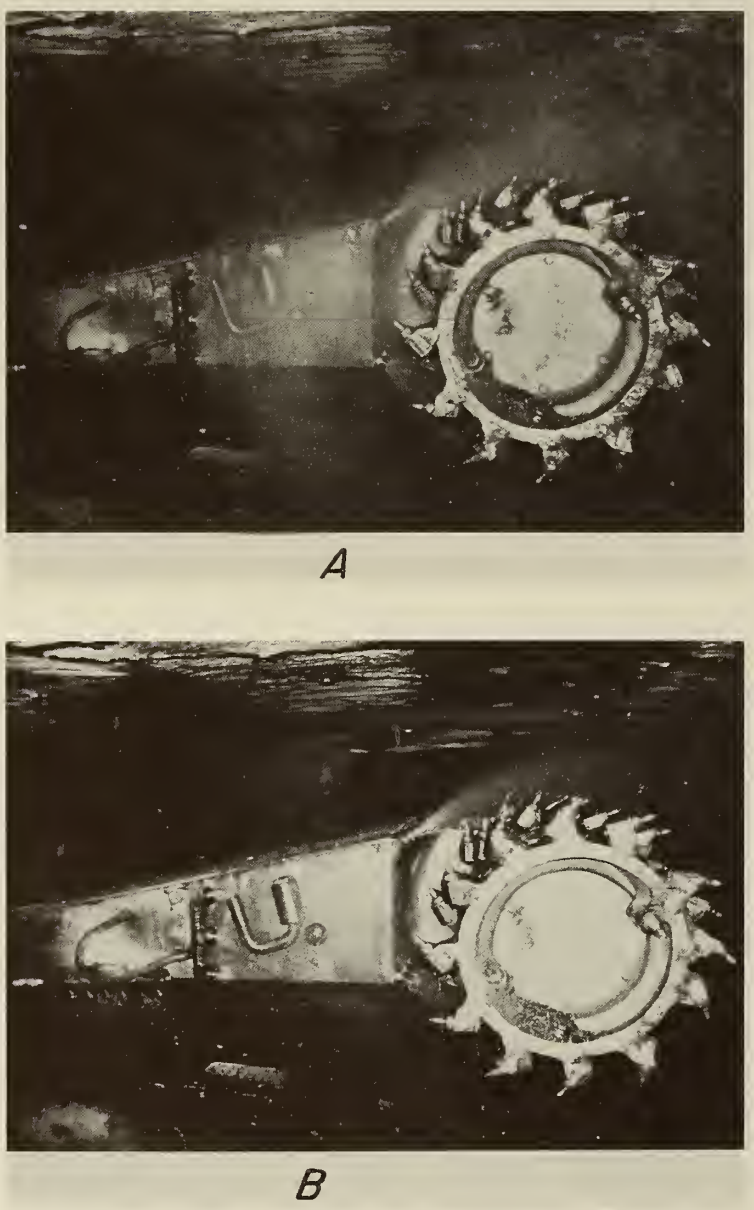

FIGURE 5. - Water sprays on Lee Norse 26H continuous-mining machine. BD5 nozzles *A*, at 70 lb/in^2, and *B*, at 15 lb/in^2.

FOAM

High-expansion foam may suppress dust during cutting at the face by blanketing the cutting site and physically preventing dust from becoming airborne. Studies to test this theory have been inconclusive because of insufficient underground testing. The Bureau therefore contracted for two field studies (10, 16) to obtain definitive results on the usefulness of foam; tests were conducted with three ripper continuous mining machines (fig. 6), one auger, and one longwall shearer. In most cases, foam suppressed about 20 percent more respirable dust than conventional water sprays, although 60 percent more dust was suppressed in one case. The foam was particularly effective in suppressing the larger float dust particles. However, cost was burdensome (5 to 10 cents/ton) and special

FIGURE 6. - Foam on continuous-mining machine.

equipment is required. In addition, the solution may refoam in the washing plant. Thus, although the foam was well received by mine personnel, the cost, special equipment, inconvenience, and possible refoaming must be balanced against the usually modest improvement in dust control.

SUMMARY

A new nonclogging system inserted in the water line reduced field maintenance of spray nozzles on continuous-mining machines more than 90 percent.

Improved conventional water spray systems to reduce respirable dust and/or water consumption can be custom designed for specific field applications using simple, inexpensive, conventional spray nozzles. Depending upon the situation, high line pressures and high water flow rates are often unnecessary for controlling respirable dust, and can be detrimental to the mining operation. Field applications of improved water sprays are as follows:

1. Transfer point.--Moistening the underside of the belt can reduce dust more than 60 percent. Improved spray systems to moisten the belt or the broken coal on the belt can be designed but must be field tested.

2. Longwall plow.--An improved spray system can eliminate drips and reduce mist and puddles.

3. Ripper continuous-mining machine.--To date effectiveness depends upon the specific mining machine. Dust has been reduced up to 50 percent by relocating spray nozzles from the top of the boom to the bottom of the boom, and water consumption has been reduced 33 percent by using new spray nozzles.

Exotic techniques such as steam, wetting agents, special water sprays, and foam appear to improve dust control beyond that achieved with conventional water sprays, but the added expense and inconvenience may not be justified.

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PERSONAL PROTECTION AGAINST RESPIRABLE DUST

by

Thomas E. Rosendahl[1]

ABSTRACT

This Bureau of Mines report reviews new developments in personal protection of coal miners from respirable dust in the work environment. The devices discussed are improved face mask respirators, air-supplied mask and helmet hardware utilizing clean-air sources, and two air-curtain protection systems developed under contract by the Bureau of Mines. Several portable units have recently been developed for the completely mobile worker, but these involve a face mask. An air curtain incorporated in a helmet was developed by the Bureau for the semimobile worker and eliminates the need for a face mask or shield. Finally, for fixed locations, a Bureau-developed canopy air-curtain system can protect a miner from dust without physical contact while he sits under the protective canopy.

INTRODUCTION

Engineering control of respirable dust in the mine environment is the ultimate dust control technique; however, personal protection devices can serve as an interim measure or as a last alternative for mine environments that are intractable to engineering dust control techniques.

This report reviews developments in personal protection in the mining industry. The following devices are discussed: simple filtering face mask respirators, machine-mounted respirators, several portable powered respirators, and finally a helmet air curtain and a canopy air curtain developed for the Bureau under contract.

FILTERING FACE MASKS

Filtering face mask respirators for personal protection are well known to the mining industry. A wide variety of face masks have been developed. They usually consist of a soft material shaped to cover the nose and mouth of the individual and include a filtration system that removes the environmental dust.

Face masks are relatively inexpensive, highly effective when used properly, and easy to maintain by the wearer. However, filtering face masks have the definite disadvantages of high breathing resistance with increased dust loading on the filter, leakage from imperfect matching of facepiece to facial contours, facial irritation, and interference with voice communication and spitting.

[1]Mechanical engineer, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

Nevertheless, new face mask hardware is continually being developed. For example, between July 1974 and June 1975, 12 supplied-air respirators and 22 dust, fume, and mist repirators were certified. A complete list of the manufacturers of certified personal protection hardware is given in the appendix at the end of this paper. Current information on new commercial face masks can be obtained from these manufacturers.

POWERED FACE MASK SYSTEMS

The following section discusses two machine-mounted and five belt-mounted powered face mask systems.

Pressure Demand Face Mask System

The National Institute of Occupational Safety and Health (NIOSH) has developed a system that utilizes machine-powered support hardware to filter the environmental dusty air and provide filtered air to a facepiece (fig. 1). The system consists of a machine-mounted compressor and air cleaner, an umbilical hose, and a half-mask facepiece. The compressor is a hydraulic air compressor producing an airflow of 3.75 ft^3/min at an output pressure of 60 lb/in^2. Dusty air enters through a precleaning cyclone and flows through the compressor into the air cleaner. The air cleaner contains two cyclone separators and one cartridge-type fibrous filter. The clean air is delivered to

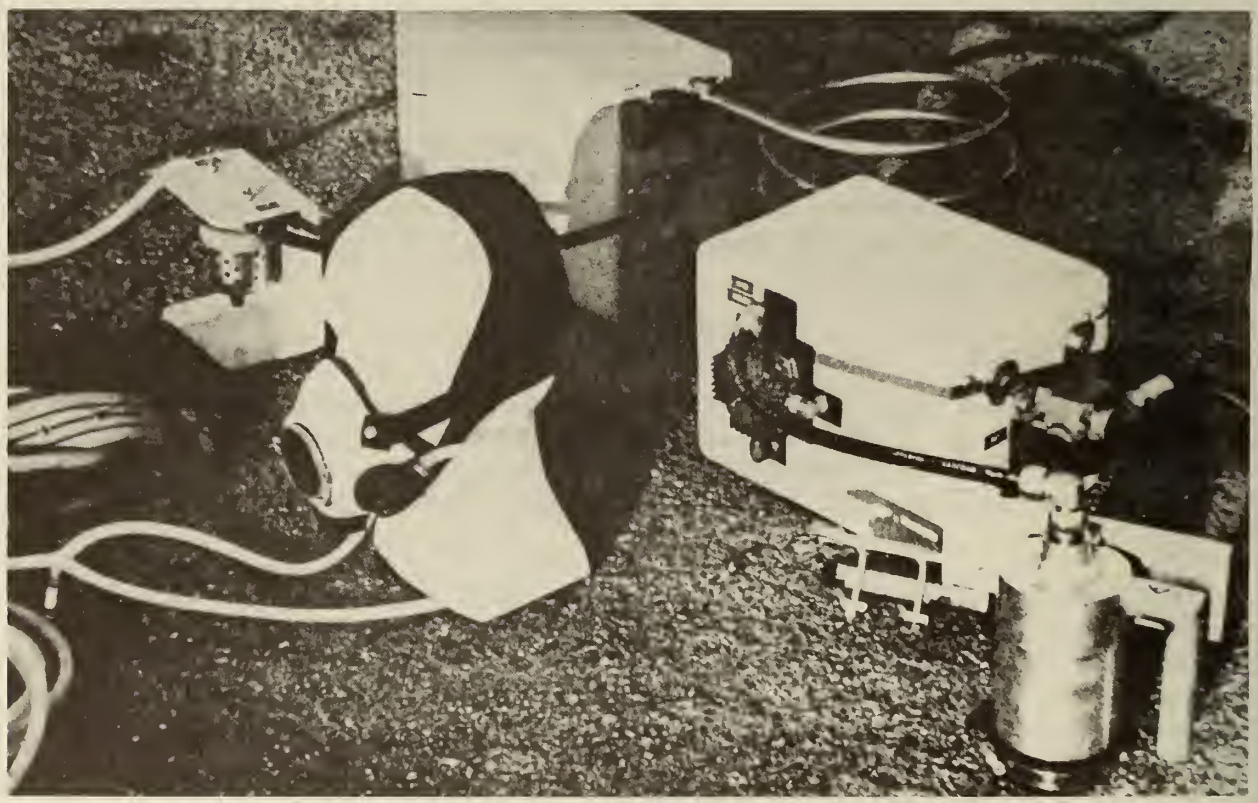

FIGURE 1. - NIOSH machine-mounted air supply, half-mask system.

the half mask through a 15-foot length of reinforced 1/2-inch-diameter umbilical hose. An automatic quick disconnect for emergencies is incorporated in the umbilical hardware at the belt.

The system contains a pressure-demand regulator for providing clean air on demand, thereby eliminating the high breathing resistance sometimes encountered with filtering face masks. The facepiece incorporates a swing-away front panel for speech, spitting, etc., and a suspension harness compatible with the coal miner's helmet.

However, the system has the usual physical disadvantages associated with a face mask, and also the psychological and physical disadvantage of the umbilical hose connecting the person to the machine. Field tests in an underground coal mine have not been conducted.

Cryogenically Supplied Face Mask System

A system (fig. 2) developed by Essex Cryogenics, Inc., St. Louis, Mo., utilizes a half-mask facepiece, but the support package supplying clean air is a cryogenic air-storage system. The system consists of the cryogenic storage unit, an air controlling device, a demand regulator, an umbilical hose to the wearer, and the half-mask respirator. In operation, the coal mine operator carries a newly charged cryogenic support system into the mine at the

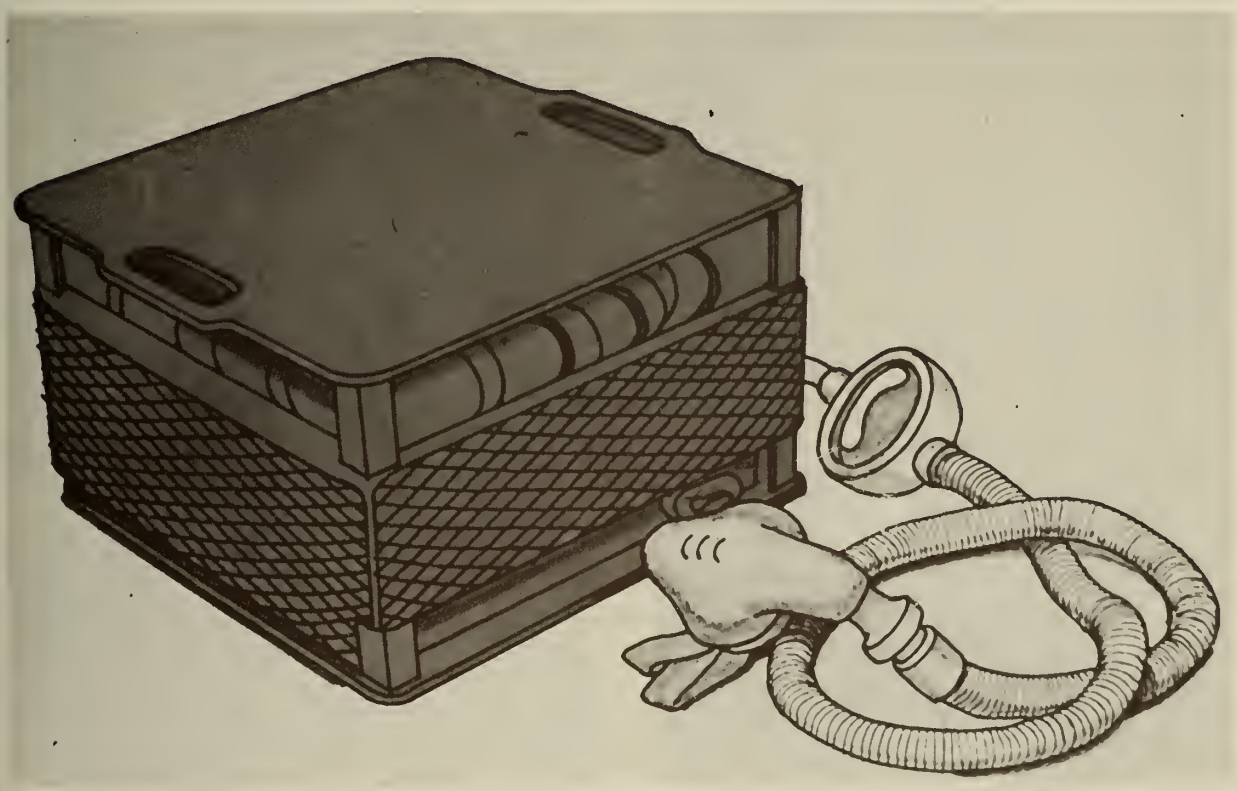

FIGURE 2. - Essex cryogenic-air-supply, half-mask system.

beginning of the workday. The system mounts on the mining machine in the vicinity of the machine operator, and the half-mask system is conveniently attached to the support hardware. Air is provided upon demand to the mask through a heat exchanger and regulator system. A quick disconnect is incorporated in the umbilical system.

The advantages and disadvantages of this system are similar to those of the NIOSH pressure-demand system. Testing of this system in an underground coal mine by United States Steel Corp. indicates that acceptance of this system has been very limited.

Belt-Powered Face Mask Systems

Several face mask systems recently developed are powered by a belt-mounted battery, thus avoiding the distinct disadvantages associated with the umbilical hose of the preceding machine-powered systems.

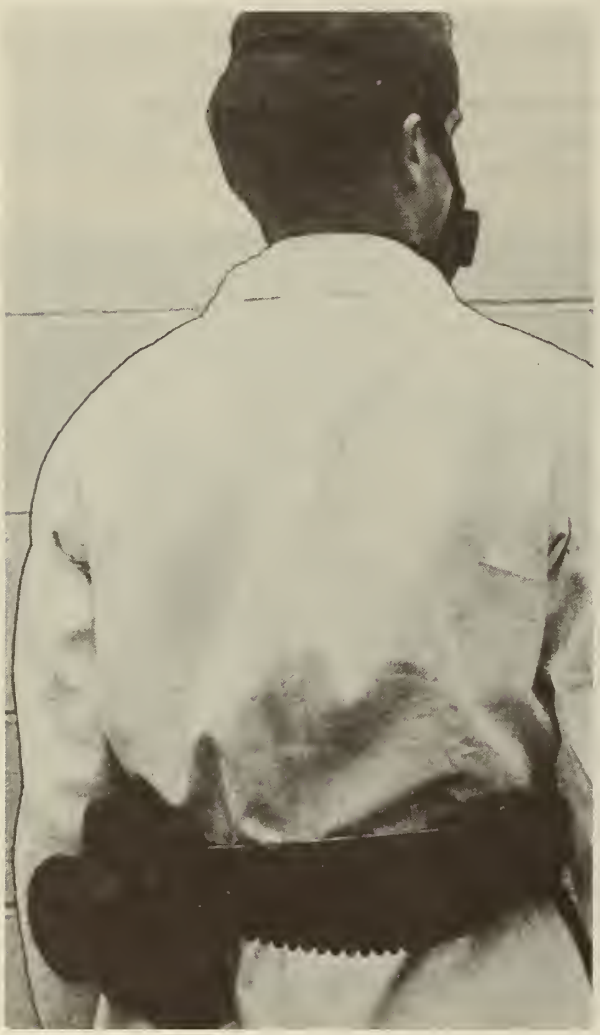

FIGURE 3. - Harvard belt-powered face mask.

FIGURE 4. - Martindale belt-powered face mask.

FIGURE 5. - Aerateur belt-powered face mask.

The American Iron and Steel Institute through Harvard University developed a belt-mounted pack containing a battery, motor, and blower (fig. 3). The clean air is ducted to a face mask. The powerpack weighs approximately 2-1/2 pounds; the breathing hose, mask, and belt weigh an additional 1-3/4 pounds. The unit is presently being evaluated at a number of coke ovens in the United States.

Martindale Electric Ltd. (London) has developed a harness-mounted power unit (fig. 4) to be used with a face mask or a plastic hood. The power unit contains a motor and blower, battery, roughing prefilter, and a high-efficiency final filter. The clean air is ducted to a face mask. The power unit weighs approximately 5-3/4 pounds, and the associated ducting and mask, another 2-1/2 pounds. The battery is intended to provide power for 8 hours of operation. The unit is stated to have varied industrial applications.

The Aerateur BQ unit was developed by the Center for Mining Medical Studies of the Nord Pas de Calais coalfields in France. The system (fig. 5) consists of a belt-mounted battery and face mask; the face mask contains an electric motor, fan, and dust filter. The complete facepiece assembly weighs approximately 12 ounces. A standard dry-cell battery is said to provide for up to 70 hours of operation. The assembly is produced by Fenzy & Cie (Paris) and is distributed in the United States by Safety and Supply Co., Seattle, Wash. The distributor states that the filter has an average collection efficiency of 98.5 percent when tested

with submicrometer dust. Over 1,000 units are being evaluated in the French coalfields.

The Mine Safety Appliance Co. (MSA), Pittsburgh, Pa., is introducing a similar belt-powered respirator. This system consists of a belt-mounted package 6-3/4 inches by 6-7/8 inches by 3 inches that can be used with either a full face mask or one of two styles of half masks. The unit utilizes NiCd rechargeable batteries intended to provide 4 hours of operation. The airflow to the mask is sufficient to maintain a positive pressure; that is, leakage between the mask and face is outward under all normal conditions. A 1-inch-ID hose connects the support system to the mask. The unit is expected to be commercially available in 1977 after NIOSH and MESA approval.

Helmet System

The Safety in Mines Research Establishment (SMRE) in England has developed a powered helmet system with a plastic shield (fig. 6). This system is unique because the support hardware for providing the filtered air is packaged in the helmet. Power for the system is provided by the cap lamp battery. This design eliminates the need for an umbilical airhose from the belt, but a small electrical cord from the belt battery pack to the back of the helmet is still required. Dusty air enters the helmet through a rear entrance port, passes through a prefilter assembly that removes the coarse material, and then passes through the fan into a final filter assembly located between the head of the individual and the outer helmet shield. The clean air flows over the face of the individual behind a plastic shield.

A protection efficiency of at least 90 percent was reported under laboratory conditions. Underground field tests have been conducted in the United Kingdom. Results apparently have been favorable, although problems associated with impaired vision owing to dust particles on the face shield may arise.

FIGURE 6. - SMRE belt-powered helmet system.

Units are expected to become available in the United States in 1977 from Racal Airstream, Inc., Rockville, Md.

HELMET AIR CURTAIN

Under a Bureau of Mines contract, a helmet air-curtain system was developed that eliminates the face mask or the plastic face shield (fig. 7). A high-velocity linear air jet is ejected down from the brim of the helmet to establish an air curtain in front of the face. Low-velocity clean air flows down behind the curtain for breathing. The system includes a machine-mounted fan and filter assembly, an umbilical hose to the wearer's helmet, and a miner's helmet modified to form the air curtain protection. A quick disconnect assembly is provided in the umbilical hose at the belt to automatically disconnect from the support hardware in case of emergency. Laboratory tests indicated that the helmet air curtain system provides a 99-percent reduction of respirable coal mine dust.

The protective envelope of the air curtain is shown in figure 8, which shows a dust cloud impacting against the curtain at 100 ft/min. The dark area in front of the face is the zone of protection created by the air curtain.

The complete hardware for mine applications is shown in figure 9. The fan and filter support system was approximately 9 inches in diameter and 19 inches long. It is usually positioned on a mining machine under the

FIGURE 7. - Bureau of Mines machine-mounted helmet air-curtain concept.

FIGURE 8. - Air-curtain helmet system showing the zone of protection.

FIGURE 9. - Air-curtain helmet hardware.

operator's seat or in back of the operator. Throughout all of the testing, hydraulic power from the mining machine was used to power the support system.

The helmet air curtain eliminates the need for a mask or plastic shield to cover the nose and the mouth and allows unrestricted oral communications, spitting, etc. However, field tests in underground coal mines indicated that most continuous-miner operators did not like to be connected through the umbilical connection to the mining machine. A second problem is that the protection achieved by the system cannot be measured with the conventional gravimetric dust-sampling hardware used to determine compliance. Nevertheless, for occupations both aboveground and underground where the worker must be semimobile, the helmet air curtain would appear to offer distinct advantages over other personal protection systems. Development hardware is available through the Bureau of Mines.

CANOPY AIR CURTAIN

In view of the undesirability of the umbilical cord of the helmet air curtain, a Bureau contract developed a canopy air curtain system. This system (fig. 10) consists of a machine-mounted, hydraulically driven, fan/filter assembly and a canopy-mounted air diffuser that provides a gentle downflow of clean air over the head and shoulders of the operator. This device eliminates the need for a face mask or shield and also eliminates the umbilical hose

FIGURE 10. - Bureau of Mines machine-mounted canopy air-curtain concept.

FIGURE 11. - Canopy air-curtain system installed over a continuous-miner operator.

between the mining machine and the individual. In laboratory tests, this system provided better than a 90-percent reduction of respirable dust.

Figure 11 shows the canopy air-curtain system installed on a continuous-mining machine. Field results with this system in coal mines have demonstrated that the gravimetrically measured level of personal dust exposure can be reduced up to 70 percent over an 8-hour day. This lower level of protection compared with laboratory test results is due to the individual dismounting from the machine to work at other parts of the face during an 8-hour workday. Also, as the individual leans to the outside of the machine to get a better view of the cutting operation, the level of protection will be reduced. This can be resolved by mounting the system to create a horizontal crossflow instead of the vertical downdraft.

One difficulty observed in the field testing was that high-velocity ventilation air (above 200 ft/min) such as at a longwall mining face can distort the downdraft air curtain and degrade its protective capability. However, the air diffuser is adaptable and could be located on the upwind side of the individual in a cross flow mode to take advantage of the ventilation currents. Also, both the surface area and the velocities can be modified to provide a much larger zone of protection.

The canopy air-curtain system for coal mining machinery is commercially available at a cost of about $1,500. The U.S. supplier is Donaldson Co., Inc., Minneapolis, Minn.

CONCLUSIONS

Several new personal protection systems for use by the coal mining industry have recently been developed. Personal dust protection systems have advanced from the early face-mask and helmet systems to powered face-mask systems for mobile workers and air-curtain systems that avoid the discomfort frequently associated with mask systems.

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APPENDIX.--MANUFACTURERS AND DISTRIBUTORS OF NIOSH CERTIFIED PERSONAL PROTECTIVE EQUIPMENT THROUGH JUNE 1976

The material in this appendix was obtained from the latest available published supplement of the U.S. Department of Health, Education, and Welfare Pub. No. (NIOSH) 76-145, entitled "NIOSH Certified Equipment, December 15, 1975" and "Cumulative Supplement, June 1976, NIOSH Certified Equipment." For additional information, a single copy of each document is available from--

Division of Technical Services
National Institute for Occupational Safety and Health
Robert A. Taft Laboratories
4676 Columbia Parkway
Cincinnatti, Ohio 45226.

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TABLE A-1. - Manufacturers of personal protection hardware

Hardware category	Manufacturers[1] supplying NIOSH-approved hardware
Dust, fume, and mist respirators..	1, 3, 7, 9, 11, 15, 20, 23, 25-26, 30, 32-33.
Chemical cartridge respirators....	1, 3, 7, 9, 11, 15, 20, 23, 25-27, 31-33.
Gas masks.....	12, 20, 26, 32.
Supplied-air respirators.....	1-3, 5-8, 10, 13-14, 16-18, 20, 22-24, 26, 29-31, 33.
Self-contained breathing apparatus (SCBA).	4, 12, 16, 18-21, 26, 28-29.

[1]Numbers refer to items in the following list of manufacturers and distributors.

Names and Addresses of Manufacturers and Distributors

1. American Optical Corp., Safety Products Div., 100 Cannal St., Putnum, Conn. 06260.
2. Anderson Manufacturing Co., 1014 Fox Chase Rd., Rockledge, Pa. 19111.
3. Binks Manufacturing Co., 9201 West Belmont Ave., Franklin, Park, Ill. 60131.
4. BioMarine Industries, Inc., 303 West Lancaster Ave., Devon, Pa. 19333.
5. Bowen Tools, Inc., P.O. Box 3186, Houston, Tex. 77001.
6. Bullard, E. D., Co., 2680 Bridgeway, Sausalito, Calif. 94965.
7. Cesco Safety Products, Parmalee Industries, Inc., P.O. Box 1237, Kansas City, Mo. 64141.
8. Clemco Industries, 2177 Jerrold Ave., San Francisco, Calif. 94124.
9. Cover, H. S., Co., 107 East Alexander St., Buchanan, Mich. 49107.
10. Deane & Co., 190 Oneida Dr., Point Claire, Quebec, Canada.
11. DeVilbiss Corp., Toledo, Ohio 43601.
12. Drägerwerk, AG, D-24 Luebeck 1, Postfach 1339, Federal Republic of Germany.

13. Empire Abrasive Equipment Corp., 9990 Gantry Rd., Philadelphia, Pa. 19115.
14. Encon Manufacturing Co., 4914 Dickson St., Houston, Tex. 77007.
15. Glendale Optical Co., 130 Crossways Park Dr., Woodbury, N.Y. 11797.
16. Globe Safety Products, Inc., 125 Sunrise Pl., Dayton, Ohio 45407.
17. Kelco Sales & Engineering Co., P.O. Box 422, Norwalk, Calif. 90650.
18. Lear Siegler, Inc., 714 North Brookhurst St., Anaheim, Calif. 92803.
19. Lockheed Missiles & Space Co., 1111 Lockheed Way, Sunnyvale, Calif. 94088.
20. Mine Safety Appliances Co., 201 North Braddock Ave., Pittsburgh, Pa. 15208.
21. National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Tex. 77058.
22. Pauli & Griffin, 137 Utah Ave., South San Francisco, Calif. 94080.
23. Pulmosan Safety Equipment Corp., 30-48 Linden Pl., Flushing, N.Y. 11354.
24. Quaker State Machine & Supply Co., P.O. Box 605, Rushland, Pa. 18956.
25. Safeline Products, P.O. Box 550, Putnam, Conn. 06260.
26. Scott Aviation, Div. of ATO, Inc., Lancaster, N.Y. 14086.
27. Sellstrom Manufacturing Co., 59 East Van Buren St., Chicago, Il1. 60605.
28. Siebe Gorman, Ltd., Chessington, Surrey, England.
29. SurvivAir, Div. of U.S. Divers Co., 3323 West Warner Ave., Santa Ana, Calif. 92702.
30. 3M Company, 3M Center, St. Paul, Minn. 55101.
31. United States Safety Service, Parmalee Industries, Inc., P.O. Box 1237, Kansas City, Mo. 64141.
32. Welsh Manufacturing Co., 9 Magnolia St., Providence, R.I. 02909.
33. Willson Products Div., ESB Inc., P.O. Box 622, Reading, Pa. 19603.

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